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ALTITUDE DEVELOPMENTAL TESTING OF THE J-2S ROCKET ENGINE IN ROCKET DEVELOPMENT TEST CELL (J-4) (TESTS J-4-1902-13 THROUGH J4-1902-15)

C. H. Kunz and H. J. Counts, Jr.
ARO, Inc.

June 1970

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ENGINE TEST FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
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Per AF letter dtd 12 July 74 signed William O. Cole

FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC) (PM-EP-J), under Program Element 921E, Project 9194.

The results of the tests presented were obtained by ARO, Inc., (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract F40600-69-C-0001. Program direction was provided by NASA/MSFC; technical and engineering liaison was provided by North American Rockwell Corporation, Rocketdyne Division, manufacturer of the J-2S rocket engine, and McDonnell Douglas Astronautics Company, manufacturer of the S-IVB stage. The testing reported herein was conducted between May 15 and June 4, 1969, in Rocket Development Test Cell (J-4) of the Engine Test Facility (ETF) under ARO Project No. KA1902. The manuscript was submitted for publication on March 27, 1970.

This technical report has been reviewed and is approved.

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ABSTRACT

Seven firings of the Rocketdyne J-2S rocket engine (S/N J-112-1C) were conducted during test periods J4-1902-13, -14, and -15 on May 15 and 22, and June 4, 1969, respectively. The major objectives of these test periods were: (1) to determine a method of increasing fuel turbine inlet temperature in order to prevent turbine icing and attain stable high thrust idle-mode operation, and (2) to demonstrate post-main-stage transition to low thrust idle mode. Changes in injector mixture ratio during high thrust idle-mode operation from 1.55 to 2.02 increased inlet temperature, in general, from 85 to 190°F for the fuel turbine, and from 45 to 95°F for the oxidizer turbine. Stable high thrust idle-mode operation was attained on five firings which had fuel turbine inlet temperatures above 160°F. Satisfactory transition to post-main-stage low thrust idle mode was accomplished.

CONTENTS

APPENDIXES

NOMENCLATURE

A	Area, in. sq
ASI	Augmented spark igniter
CCP	Customer connect panel
C_D	Discharge coefficient
EBW	Exploding bridgewire
FM	Frequency modulation
MFV	Main fuel valve
MOV	Main oxidizer valve
O/F	Propellant mixture ratio, oxidizer to fuel, by weight
S/N	Serial number
SPTS	Solid-propellant turbine starter
T/C	Thrust chamber
t_0	Time at which helium control and idle-mode solenoids are energized; engine start
VSC	Vibration safety counts, defined as engine vibration in excess of 150 g rms in a 960- to 6000-Hz frequency range

SUBSCRIPTS

f	Force
m	Mass
t	Throat

SECTION I
INTRODUCTION

Testing of the Rocketdyne J-2S rocket engine using an S-IVB battleship stage has been in progress at AEDC since December 1968. Reported herein are the results of the seven engine firings conducted during test periods J4-1902-13, -14, and -15 on May 15 and 22, and June 4, 1969, respectively, utilizing engine S/N J-112-1C. The major objectives of these test periods were to: (1) determine a method of increasing fuel turbine inlet temperature in order to prevent icing and attain stable high thrust idle-mode operation, and (2) demonstrate post-main-stage transition to low thrust idle mode.

The firings were accomplished in Rocket Development Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Engine Test Facility (ETF). The firings were accomplished at pressure altitudes ranging from 94,000 to 99,000 ft (geometric pressure altitude, Z, Ref. 1) at engine start. Data collected to accomplish the test objectives are presented herein. The results of the previous test periods are presented in Ref. 2.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article was a J-2S rocket engine (Fig. 3) designed and developed by Rocketdyne Division of North American Rockwell Corporation. The engine uses liquid oxygen (LOX) and liquid hydrogen as propellants and is designed to operate either in idle mode at a nominal thrust of 5000 lbf and mixture ratio of 2.5, or at main stage at any precalibrated thrust level between 230,000 and 265,000 lbf at a mixture ratio of 5.5. The engine design is capable of transition from idle-mode to main-stage operation after a minimum of 1-sec idle mode; from main stage the engine can either be shut down or make a transition back to idle-mode operation before shutdown. An S-IVB battleship stage was used to supply propellants to the engine. A schematic of the battleship stage is presented in Fig. 4.

Listings of major engine components and engine orifices for this test period are presented in Tables I and II, respectively (Appendix II). All engine modifications and component replacements performed during this report period are presented in Tables III and IV, respectively.

2.1.1 J-2S Rocket Engine

The J-2S rocket engine (Figs. 3 and 5, Ref. 3) features the following major components:

1. Thrust Chamber - The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in.-diam combustion chamber with a throat diameter of 12.192 in., a characteristic length (L^*) of 35.4, and a divergent nozzle with an expansion ratio of 39.62. Thrust chamber length (from the injector flange to the nozzle exit) is 108.6 in. Cooling

is accomplished by the circulation of engine fuel flow downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector and by film cooling inside the combustion chamber.

2. Thrust Chamber Injector - The injector is a concentric-orificed (concentric fuel orifices around the oxidizer post orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 19.2 and 5.9 sq in., respectively. The oxidizer portion is compartmented, the outer compartment supplying oxidizer during main-stage operation only. The porous material forming the injector face allows approximately 3.5 percent of main-stage fuel flow to transpiration cool the face of the injector.

3. Augmented Spark Igniter - The augmented spark igniter unit is mounted on the thrust chamber injector and supplies the initial energy source to ignite propellants in the main combustion chamber. The augmented spark igniter chamber is an integral part of the thrust chamber injector. Fuel and oxidizer are ignited in the combustion area by two spark plugs.

4. Fuel Turbopump - The fuel turbopump is a one and one-half stage, centrifugal-flow unit, powered by a direct-drive, two-stage turbine. The pump is self-lubricated and nominally produces, at the 265,000-lbf thrust rated condition, a head rise of 60,300 ft of liquid hydrogen at a flow rate of 9750 gpm for a rotor speed of 29,800 rpm.

5. Oxidizer Turbopump - The oxidizer turbopump is a single-stage, centrifugal-flow unit, powered by a direct-drive, two-stage turbine. The pump is self lubricated and nominally produces, at the 265,000-lbf thrust rated condition, a head rise of 3250 ft of liquid oxygen at a flow rate of 3310 gpm for a rotor speed of 10,500 rpm.

6. Propellant Utilization Valve - The motor-driven propellant utilization valve is a sleeve-type valve which is mounted on the oxidizer turbopump and bypasses liquid oxygen from the discharge to the inlet side of the pump to vary engine mixture ratio.

7. Main Oxidizer Valve - The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the oxidizer high-pressure duct between the turbopump and the injector. The first-stage actuator positions the main oxidizer valve at the 12-deg position to obtain initial main-stage-phase operation; the second-stage actuator ramps the main oxidizer valve fully open to accelerate the engine to the main-stage operating level.

8. Main Fuel Valve - The main fuel valve is a pneumatically actuated, butterfly-type valve located in the fuel high-pressure duct between the turbopump and the fuel manifold.

9. Pneumatic Control Package - The pneumatic control package controls all pneumatically operated engine valves and purges.

10. Electrical Control Assembly - The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation. The logic requires a minimum of 1-sec idle-mode operation before transition to main stage.

11. Flight Instrumentation Package - The instrumentation package contains sensors required to monitor critical engine parameters. The package provides environmental control for the sensors.

12. Helium Tank - The helium tank has a volume of 4000 cu in. and provides a helium pressure supply to the engine pneumatic control system for three complete engine operational cycles.

13. Thrust Chamber Bypass Valve - The thrust chamber bypass valve is a pneumatically operated, normally open, butterfly-type valve which allows fuel to bypass the thrust chamber body during idle-mode operation.

14. Idle-Mode Valve - The idle-mode valve is a pneumatically operated, ball-type valve which supplies liquid oxygen to the idle-mode compartment of the thrust chamber injector during both idle-mode and main-stage operation.

15. Hot Gas Tapoff Valve - The hot gas tapoff valve is a pneumatically operated, butterfly-type valve which provides on-off control of combustion chamber gases to drive the propellant turbopumps.

16. Solid-Propellant Turbine Starter - The solid-propellant turbine starter provides the initial driving energy (transition to main stage) for the propellant turbopumps to prime the propellant feed systems and accelerate the turbopumps to 75 percent of their main-stage operating level. A three-start capability is provided.

2.1.2 S-IVB Battleship Stage

The S-IVB battleship stage, which is mechanically configured to simulate the S-IVB flightweight vehicle, is approximately 22 ft in diameter and 49 ft long and has a maximum usable propellant capacity of 43,000 lbm of liquid hydrogen and 194,000 lbm of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant prevalves, in the low-pressure ducts (external to the tanks)

interfacing the stage and engine, retain propellants in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Vent and relief valve systems are provided for both propellant tanks.

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen and gaseous oxygen for fuel and oxidizer tank pressurization during flight were routed to the respective facility venting systems.

2.2 TEST CELL

Rocket Development Test Cell (J-4) Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines and propulsion systems at pressure altitudes of 100,000 ft. The basic cell construction provides a 1.5-million-lbf thrust capacity. The cell consists of four major components: (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), liquid-oxygen and gaseous-helium storage and delivery systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 4.

The battleship stage and the J-2S engine were oriented vertically downward on the centerline of the diffuser/steam ejector assembly. This assembly consisted of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous-nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown. The test cell was also equipped with: (1) a gaseous-nitrogen purge system for continuously inerting the normal air in-leakage of the cell; (2) a gaseous-nitrogen repressurization system for raising test cell pressure, after engine cutoff, to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule; and (3) a spray chamber liquid-nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting and for increasing the molecular weight of the hydrogen-rich exhaust products.

2.3 INSTRUMENTATION

Instrumentation systems were provided to measure engine, stage, and facility parameters. The engine instrumentation was comprised of flight instrumentation which

was provided to verify the flight instrumentation and to measure additional engine parameters. The flight instrumentation was provided and calibrated by the engine manufacturer; facility instrumentation was initially calibrated and periodically recalibrated at AEDC. Appendix III contains a list of all measured engine test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage and capacitance-type pressure transducers. Temperature measurements were made using resistance temperature transducers and thermocouples. Oxidizer and fuel turbopump shaft speeds were sensed by magnetic pickup. Fuel and oxidizer flow rates to the engine were measured by turbine-type flowmeters which are an integral part of the engine. Vibrations were measured by accelerometers mounted on the oxidizer injector dome, thrust chamber throat, and on the turbopumps. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

The data acquisition systems were calibrated by: (1) precision electrical shunt resistance substitution for the pressure transducers and resistance temperature transducer units; (2) voltage substitution for the thermocouples; (3) frequency substitution for shaft speeds and flowmeters; and (4) frequency-voltage substitution for accelerometers and capacitance-type pressure transducer.

The types of data acquisition and recording systems used during this test period were: (1) a multiple-input digital data acquisition system scanning each parameter at 50 samples per second and recording on magnetic tape; (2) single-input, continuous-recording FM systems recording on magnetic tape; (3) photographically recording galvanometer oscillographs; (4) direct-inking, null-balance, potentiometer-type X-Y plotters and strip charts; and (5) optical data recorders. Applicable systems were calibrated before each test (atmospheric and altitude calibrations). Television cameras, in conjunction with video tape recorders, were used to provide visual coverage during an engine firing, as well as for replay capability for immediate examination of unexpected events.

2.4 CONTROLS AND SEQUENCE OF EVENTS

Control of the J-2S engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect the engine control system, major stage systems, the engine safety cutoff system, the observer cutoff circuits, and the countdown sequencer. A schematic of the engine start control logic is presented in Fig. 6. The sequence of engine events for start and shutdown is presented in Figs. 7a and b.

Low thrust idle mode was accomplished by sequencing the engine for operation with the main fuel valve, idle-mode oxidizer valve, and thrust chamber bypass valve in the open positions and the main oxidizer and hot gas tapoff valves in the closed positions. Transition from low thrust to high thrust idle mode was made by fully opening the hot gas tapoff valve and opening the main oxidizer valve to the first-stage position. Main-stage operation was accomplished from high thrust idle mode by closing the thrust chamber bypass valve and advancing the main oxidizer valve to the fully open position. Transition

from main stage to low thrust idle mode was accomplished by sequencing all valves back to their pre-main-stage low thrust idle-mode positions.

SECTION III
PROCEDURE

Preoperational procedures were begun several hours before the test period. All consumable storage sysystems were replenished; and engine inspections, leak checks, and drying procedures were conducted. Propellant tank pressurants and engine pneumatic and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers. Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer dome and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust-ducting atmosphere was inerted. At this same time, the cell nitrogen purge was initiated for the duration of the test period. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Table V presents the engine purges used during the terminal countdown and immediately following the engine firing.

SECTION IV
RESULTS AND DISCUSSION

4.1 TEST SUMMARY

Seven firings of the Rocketdyne J-2S rocket engine were conducted during test periods J4-1902-13 through 15 between May 15 and June 4, 1969. Pressure altitudes at engine start ranged from 94,000 to 99,000 ft.

The major objective of these test periods was to determine a method of increasing fuel turbine inlet temperatures in order to prevent turbine icing (as experienced during firings reported in Ref. 2) and attain stable high thrust idle-mode operation. A secondary objective was to demonstrate post-main-stage transition to low thrust idle mode. Fuel turbine inlet temperature was increased by increasing injector oxidizer-to-fuel mixture ratio. This mixture ratio increase was accomplished by variations in pump inlet pressures, thrust chamber fuel bypass flow, propellant utilization valve position, and main oxidizer valve first-stage position. The hot gas tapoff valve open position was increased from 53 to 59 deg for all three test periods. It should be noted that mixture ratios quoted herein are obtained from propellant flow rates through the injector, exclusive of fuel film coolant flow.

Test requirements and specific test results are summarized in Table VI. Start and shutdown transient operating times for selected engine valves are presented in Table VII. Figure 8 depicts engine start conditions for propellant pump inlets and helium tank. Main chamber and test cell ambient pressures, injector oxidizer-to-fuel ratio and total propellant weight flow, propellant feed system performance and thrust chamber chilldown data for all firings are presented in Figs. 9 through 36. Data presented in subsequent sections are from the digital data acquisition system, except where indicated otherwise. Primary test variables and results are summarized in the following table:

Firing J4-1902-	13A	14A	14B	14C	15A	15B	15C
High thrust idle-mode duration, sec	12.5	13.8	13.8	13.8	13.8	13.7	13.7
Oxidizer pump inlet pressures, psia	38.9	45.9	39.1	39.0	38.9	33.2	31.8
Fuel pump inlet pressures, psia	37.4	39.3	38.9	38.6	39.8	32.8	27.1
MOV first stage position, deg	11	11	11	11	12	12	12
T/C fuel bypass orifice diameter, in.	1.50	Closed	Closed	Closed	None Installed	None Installed	None Installed
Propellant utilization valve position	Null	Null	Null	Closed	Null	Null	Null
Oxidizer turbine inlet temperature, °F	60	95	80	90	90	85	45
Fuel turbine inlet temperature, °F	120	190	160	180	175	175	85
Injector O/F Ratio	1.73	1.93	1.94	2.02	1.88	1.88	1.60
Maximum chamber pressure attained, psia	260	270	250	295	310	300	300
Chamber pressure decay, psi/sec	7	None	None	None	None	None	13

4.2 TEST RESULTS

4.2.1 Firing 13A

The objective of this firing was to determine the effects of fuel bypass flow resulting from a 1.50-in. thrust chamber bypass orifice and an 11-deg main oxidizer valve first-stage position on high thrust idle-mode operation. Stable high thrust idle-mode operation was not attained with these test conditions. Main chamber pressure attained a maximum of 260 psia with a decay rate thereafter of 7 psi/sec. Fuel and oxidizer turbine inlet temperatures were 120 and 60°F, respectively, at an injector oxidizer-to-fuel ratio of 1.73 after 12.5 sec of high thrust idle-mode operation. Analysis of fuel and oxidizer turbine performance indicated that conditions were present in the oxidizer turbine which would support ice formation as shown in Fig. 37.

4.2.2 Firing 14A

The objective of this firing was to determine the effect of zero thrust chamber bypass flow and 11-deg main oxidizer valve first-stage position on high thrust idle-mode operation. Stable high thrust idle-mode operation was attained at a main chamber pressure of 270 psia. Fuel and oxidizer turbine inlet temperatures were 190 and 95°F, respectively, at an injector oxidizer-to-fuel mixture ratio of 1.93 after 13.8 sec of high thrust idle-mode operation.

4.2.3 Firing 14B

The objective of this firing was to determine the effect of reducing oxidizer pump inlet pressure on high thrust idle-mode operation. Stable high thrust idle-mode operation was attained at a main chamber pressure of 260 psia. The effect of oxidizer pump inlet pressure reduction on high thrust idle-mode operation can be seen by the following comparison. The data presented are after approximately 13 sec of high thrust idle-mode operation.

	14A	14B	Results
Oxidizer pump inlet pressure, psia	45.9	39.1	
Fuel pump inlet pressure, psia	39.3	38.9	
Main chamber pressure, psia	270	250	20-psi decrease
Injector mixture ratio, O/F	1.93	1.94	0.01 increase
Fuel turbine inlet temperature, °F	190	160	30°F decrease
Oxidizer turbine inlet temperature, °F	95	80	15°F decrease

4.2.4 Firing 14C

The objectives of this firing were to determine the effect of closing the propellant utilization valve on high thrust idle-mode operation and transition from main-stage to low thrust idle-mode operation. Stable high thrust idle-mode operation was attained at a main chamber pressure of 295 psia. The effect of propellant utilization valve position on high thrust idle-mode operation can be seen by the following comparison. The data presented are after approximately 13 sec of high thrust idle-mode operation.

	14B	14C	Results
Propellant utilization valve position	Null	Closed	
Oxidizer pump inlet pressure, psia	39.1	39.0	
Fuel pump inlet pressure, psia	38.9	38.6	
Main chamber pressure, psia	250	295	45-psi increase
Injector mixture ratio, O/F	1.94	2.02	0.08 increase
Fuel turbine inlet temperature, °F	160	180	20°F increase
Oxidizer turbine inlet temperature, °F	80	90	10°F increase

4.2.5 Firing 15A

The objective of this firing was to determine the effect of maximum thrust chamber bypass flow (attained by removing the bypass line orifice) and increasing the main oxidizer valve second-stage position to 12 deg on high thrust idle-mode operation. Stable high thrust idle-mode operation was attained at a main chamber pressure of 310 psia. Fuel and oxidizer turbine inlet temperatures were 175 and 90°F, respectively, at an injector mixture ratio of 1.88 after 13.8 sec of high thrust idle-mode operation. The combined effect of main oxidizer valve first stage position change and increase in fuel bypass flow may be seen in the following table:

	14B	15A	Results
Main oxidizer valve first-stage position, deg	11	12	
Fuel bypass orifice size, in.	2.000	Open Line	
Oxidizer pump inlet pressure, psia	39.1	38.9	

	14B	15A	Results
Fuel pump inlet pressure, psia	38.9	39.8	
Main chamber pressure, psia	250	310	60-psi increase
Injector mixture ratio, O/F	1.94	1.88	0.06 decrease
Fuel turbine inlet temperature, °F	165	178	13°F increase
Oxidizer turbine inlet temperature, °F	80	90	10°F increase

4.2.6 Firing 15B

The objective of this firing was to determine the effect on high thrust idle-mode operation of a low oxidizer pump inlet pressure (33 psia) and a nominal fuel pump inlet pressure (33 psia). Stable high thrust idle-mode operation was attained at a main chamber pressure of 300 psia. Inlet temperatures were 175°F for the fuel turbine and 55°F for the oxidizer turbine. Injector oxidizer-to-fuel mixture ratio was 1.88.

4.2.7 Firing 15C

The objective of this firing was to determine the effect of minimum oxidizer and fuel pump inlet pressures on high thrust idle-mode operation. Stable high thrust idle-mode operation was not attained. Main chamber pressure attained a maximum of 300 psia with a decay rate of 13 psi/sec thereafter. Analysis of fuel and oxidizer turbine data indicate oxidizer turbine icing was the cause of this pressure decay (Fig. 38).

4.3 HIGH THRUST IDLE-MODE OPERATION

Six previous high thrust idle-mode firings have been made at altitude conditions and are described in Ref. 2. Three of these firings were successful, and the other three experienced a significant decay in main chamber pressure after transition to high thrust idle mode. On firings which experienced chamber pressure decays, turbine inlet and exhaust gas temperatures were low enough to allow formation of ice in the turbines. As a result of the ice formation on these previous firings, the main objective of test periods 13, 14, and 15 was to develop conditions to prevent ice formation in the turbine system by increasing engine mixture ratio and the resultant tapoff gas temperature. Several methods were used to vary mixture ratio. These methods included: (1) changing pump inlet pressures, (2) varying thrust chamber fuel bypass flow, (3) varying propellant utilization valve position, and (4) increasing main oxidizer valve first-stage position. Also for the firings reported herein, tapoff valve gate open position was increased from 53 to 59 deg. The effect on mixture ratio of the previously mentioned variables are discussed in Section 4.2.

The influence injector mixture ratio has on both fuel and oxidizer turbine inlet temperatures is shown in Fig. 37. The temperatures and mixture ratios shown were those observed just before transition to main stage or engine cutoff. Mixture ratios are in the range from 1.46 to 2.02 and resulted in turbine inlet temperatures ranging from 72 to 142°F (fuel), and from 38 to 95°F (oxidizer). Firings with fuel turbine inlet temperatures below 140°F (firings 13A, 15C, and 12A) experienced a decay in main chamber pressure. Stable high thrust idle-mode operation occurred on the remaining seven firings. Analysis of fuel and oxidizer turbine temperatures on firings 13A and 15C (Figs. 38 and 39) indicate conditions existed which were conducive to ice formation. Turbine performance parameters for these firings showed that ice formed in the oxidizer turbine on test 15C.

Fuel turbine inlet temperature decreased during low thrust idle mode on all firings. This was attributed to a leaking tapoff valve. The leakage resulted in fuel turbine inlet temperatures ranging from -40 to -150°F just before transition to main stage. It is not known what effect this leakage has on turbine icing.

Detonations were observed to occur in the oxidizer dome on all firings during transition from low thrust to high thrust idle-mode operation. These detonations resulted in engine vibrations in excess of 150 g for very short durations (2 to 3 msec) on three firings (13A, 15A, and 15B). This, however, did not appear to have any adverse effects on engine operation, or result in damage to any engine components.

4.4 POST-MAIN-STAGE LOW THRUST IDLE MODE

A successful transition from main stage to low thrust idle mode was made for the first time during firing 14C. Other successful transitions were made on firings 15A and 15B. Engine ambient and combustion chamber pressures, propellant feed system performance, and thrust chamber and injector temperatures for the post-main-stage low thrust operating periods are shown in Figs. 40 through 48. As shown in these figures, post-main-stage low thrust idle mode differs markedly from pre-main-stage low thrust idle mode; it is similar to an extended shutdown transient. From 6 to 10 sec are required for chamber pressure to return to a steady-state pre-main-stage low thrust idle-mode level. It should also be noted from Fig. 49 that the head rise across both fuel and oxidizer pumps also requires from 6 to 10 sec to approximate a pre-main-stage head rise level.

4.5 ENGINE SIDE LOADS

No significant post-main-stage idle-mode side forces were experienced. Side load data recorded during firing 14C are presented in Fig. 50. These data are representative for all firings reported herein. Side loads experienced were normal and consistent with those recorded on previous firings. Post-main-stage low thrust idle-mode side forces are essentially identical to pre-main-stage values (less than 100 lbf).

SECTION V
SUMMARY OF RESULTS

The results of the seven firings of the Rocketdyne J-2S rocket engine (S/N J-112-1C) conducted during test periods J4-1902-13 through -15 between May 15 and June 4, 1969, to determine a method of increasing fuel turbine inlet temperature sufficient to prevent turbine icing and attain stable high thrust idle-mode operation, are summarized as follows:

1. Injector oxidizer-to-fuel mixture ratio was varied from 1.52 to 2.02; this resulted in turbine inlet temperatures being increased from 85 to 190°F for the fuel turbine and from 45 to 95°F for the oxidizer turbine.

2. Steady-state, high thrust idle-mode operation was attained on five of the seven firings with fuel turbine inlet temperature above 160°F (firings 14A, 15B, 14C, 15A, and 15B).

3. Steady-state high thrust idle-mode operation was not attained on two firings with fuel turbine inlet temperatures below 120°F (firings 13A and 15C).

4. Post-main-stage low thrust idle-mode operation was successfully demonstrated. It appears to require from 6 to 10 sec to approximate a pre-main-stage pump head rise level and attain a steady-state chamber pressure.

5. No significant post-main-stage idle-mode side forces were experienced (less than 100 lbf).

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APPENDIXES

I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION

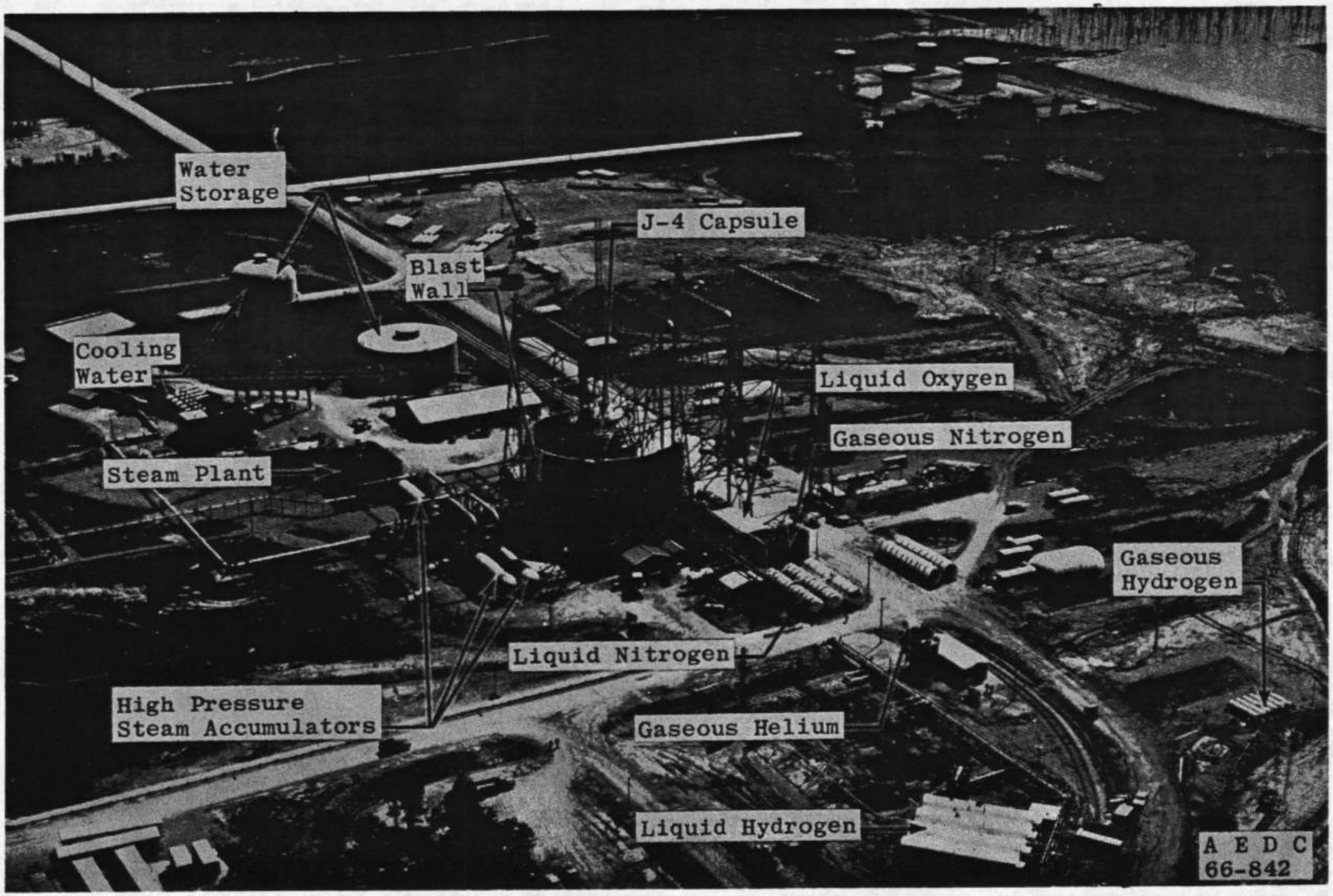


Fig. 1 Test Cell J-4 Complex

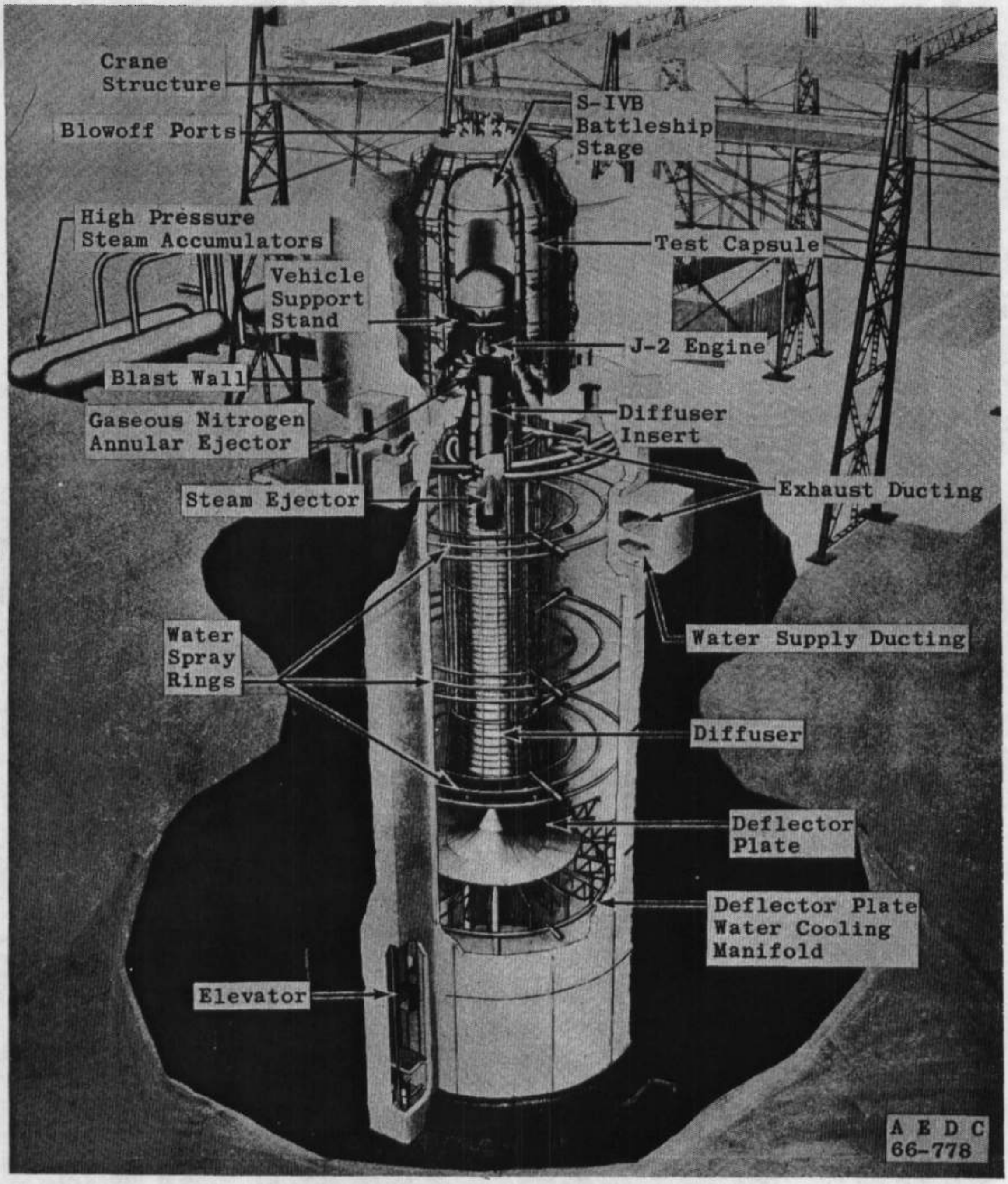


Fig. 2 Test Cell J-4, Artist's Conception

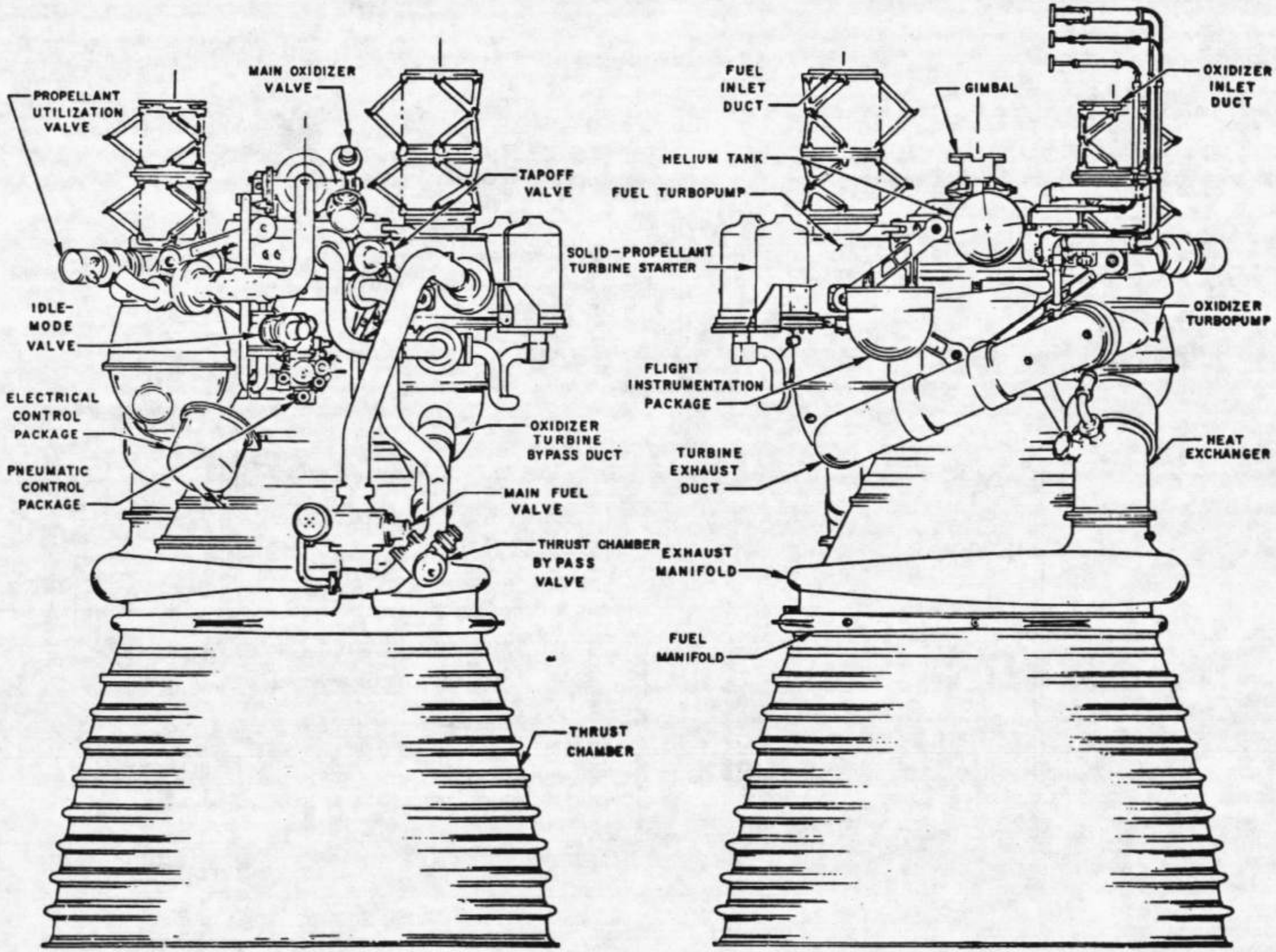


Fig. 3 J-2S Engine General Arrangement

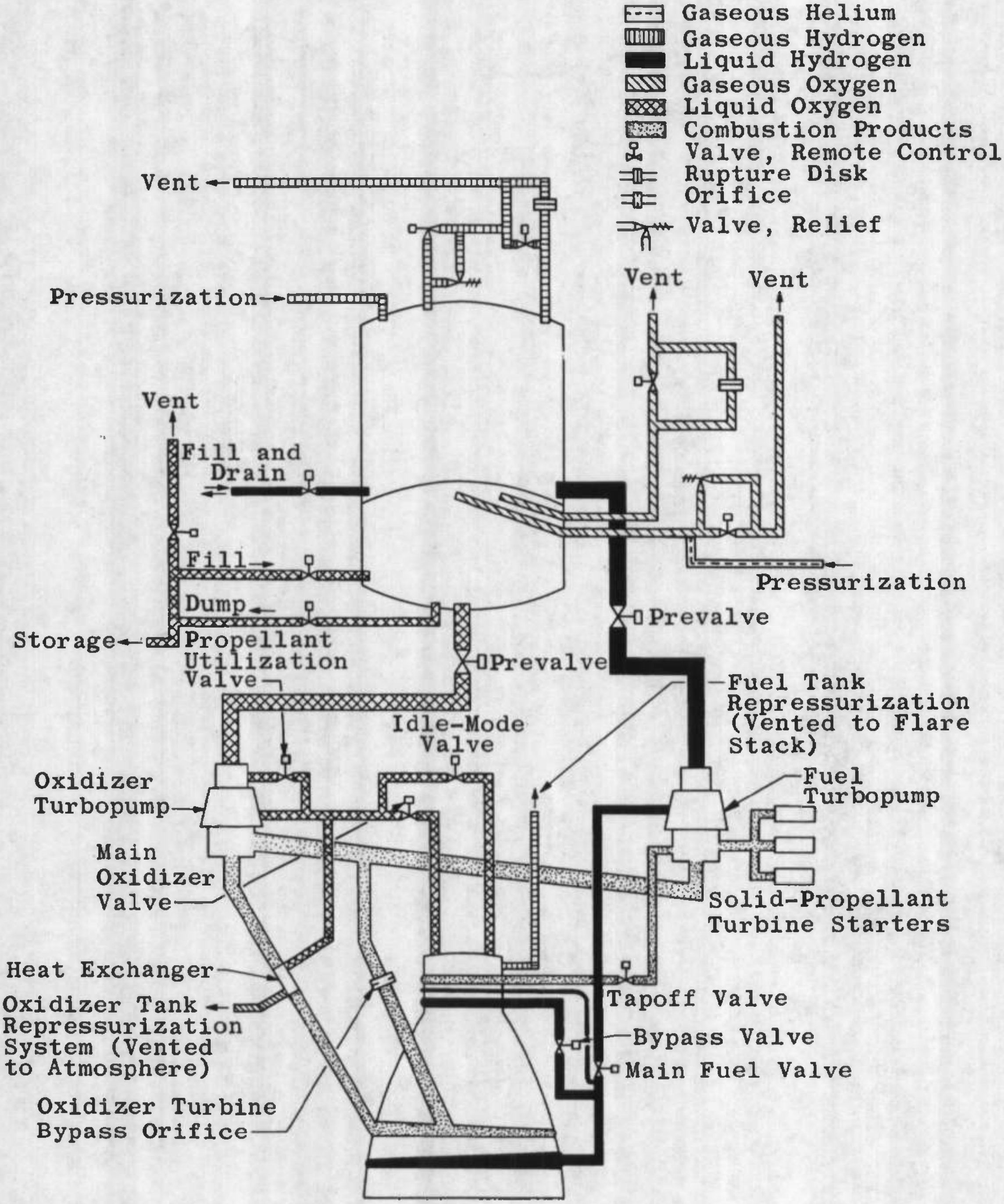
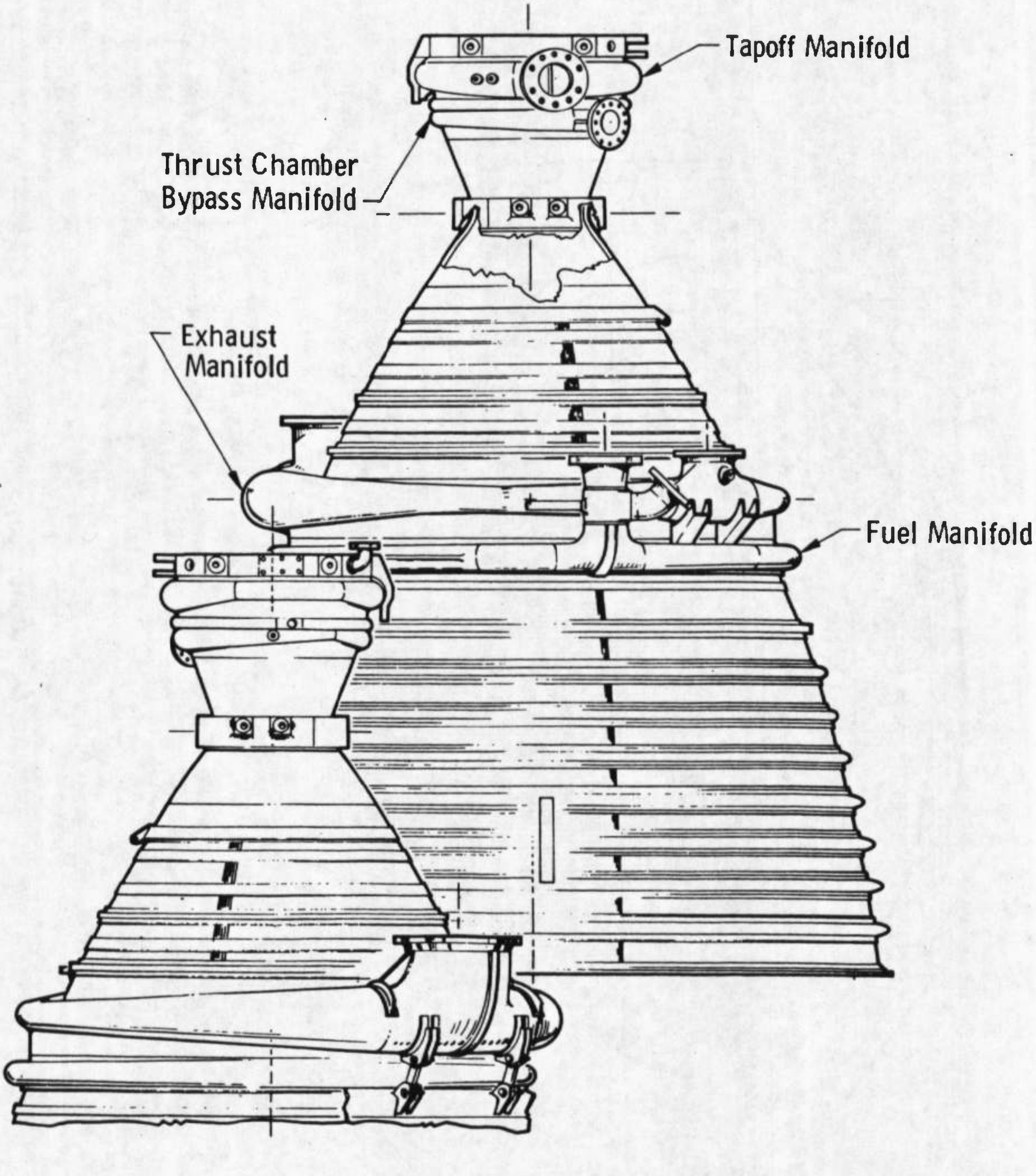
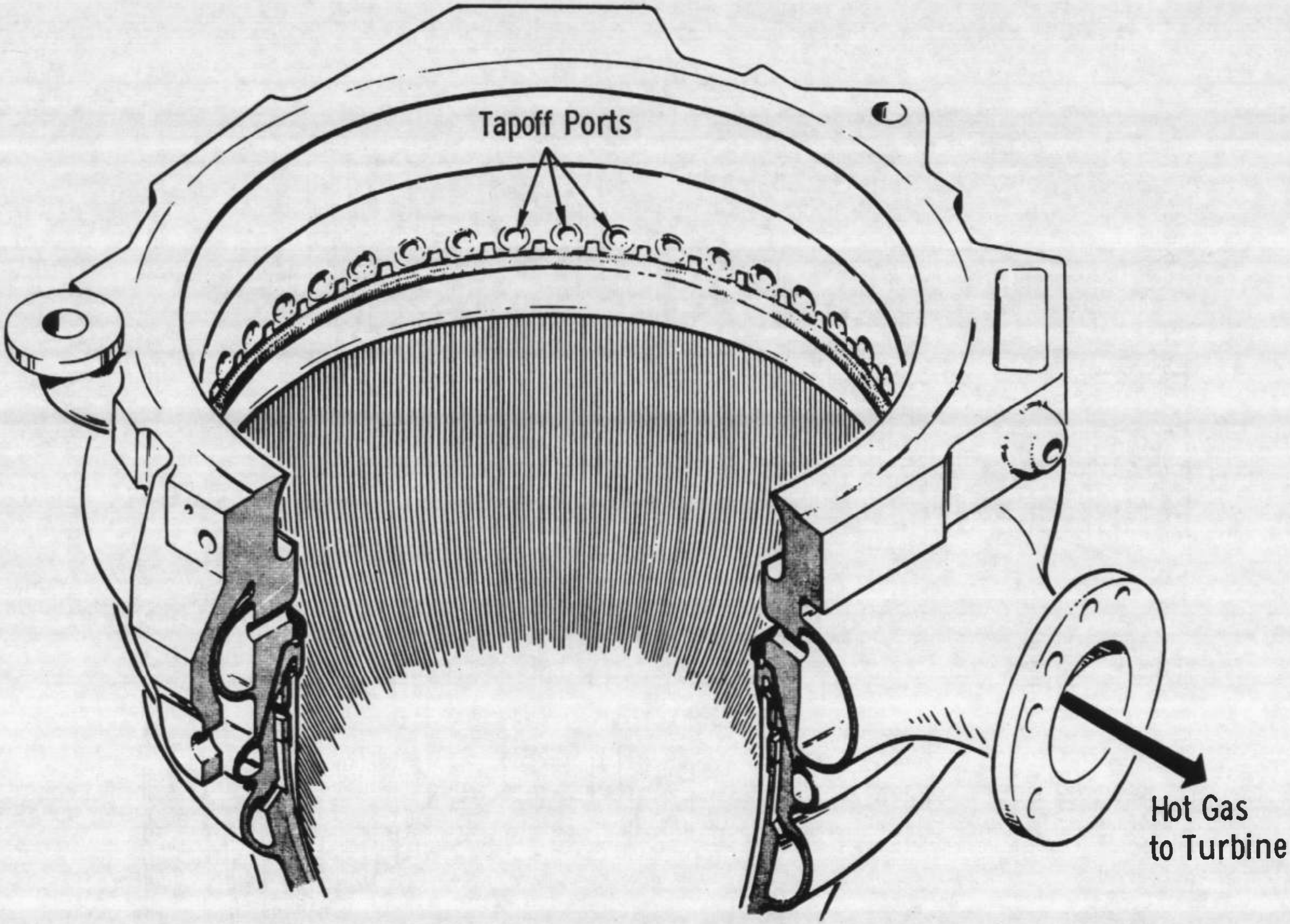


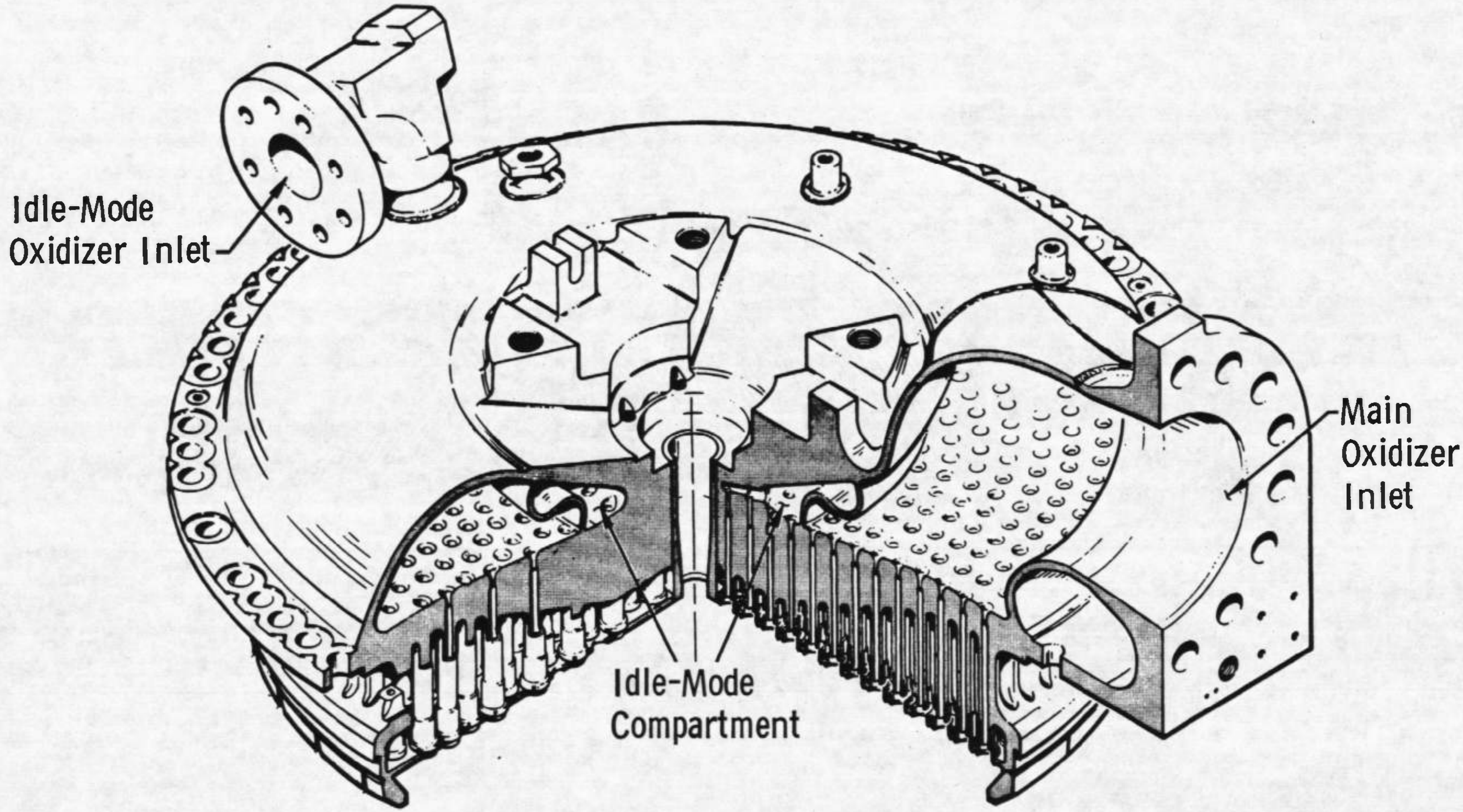
Fig. 4 S-IVB Battleship Stage/J-2S Engine Schematic



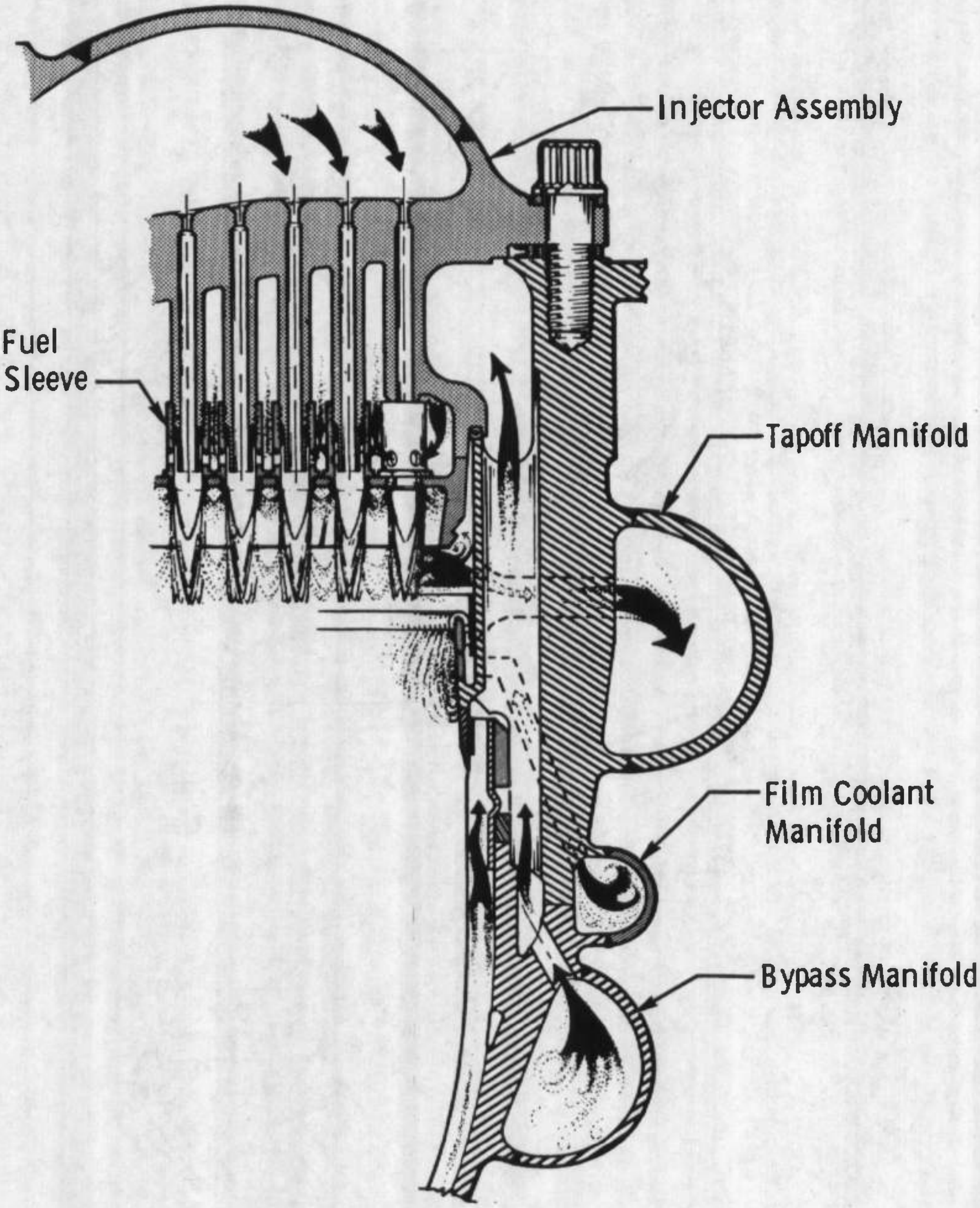
a. Thrust Chamber
Fig. 5 Engine Details



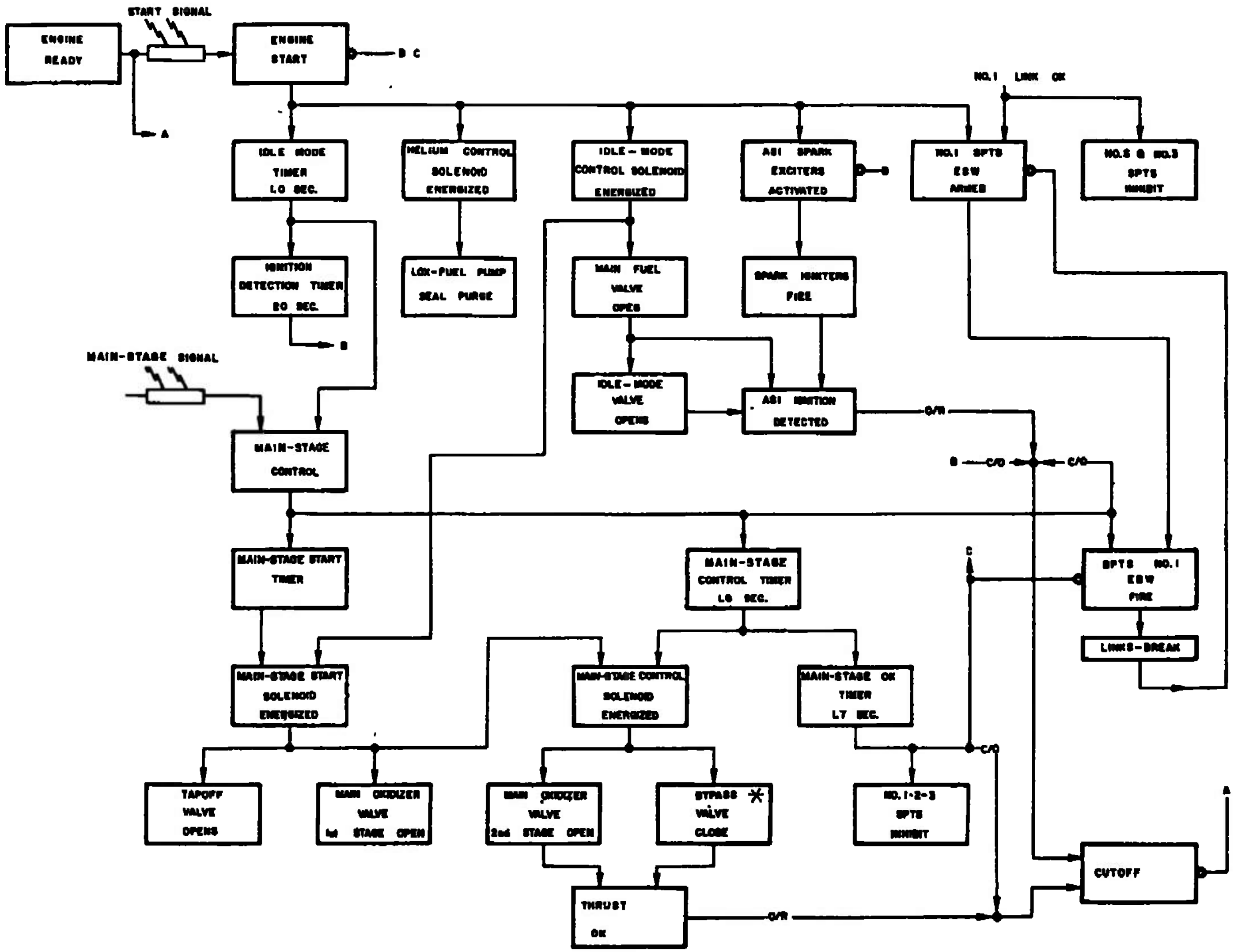
b. Combustion Chamber
Fig. 5 Continued



c. Injector
Fig. 5 Continued

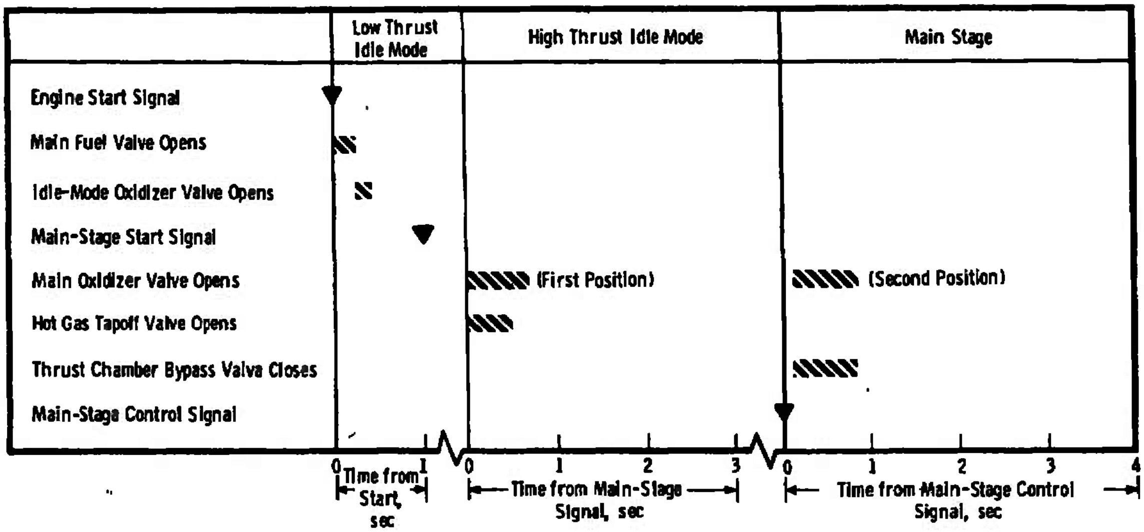


d. Injector to Chamber
Fig. 5 Concluded

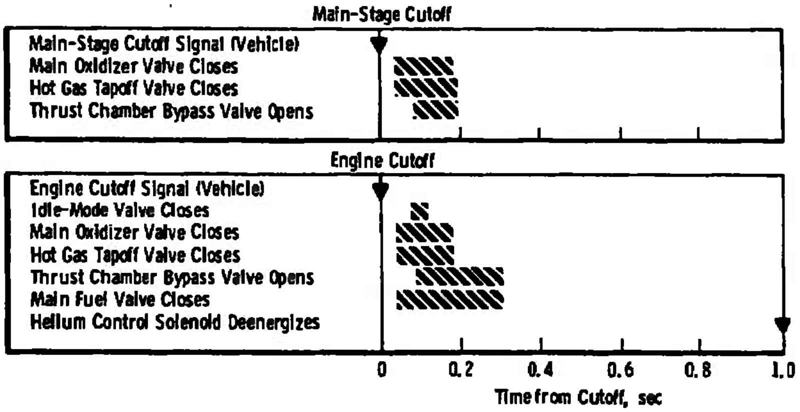


* MANUAL OPERATION OF BYPASS VALVE UTILIZED ON TEST 14

Fig. 6 Engine Start Logic Schematic

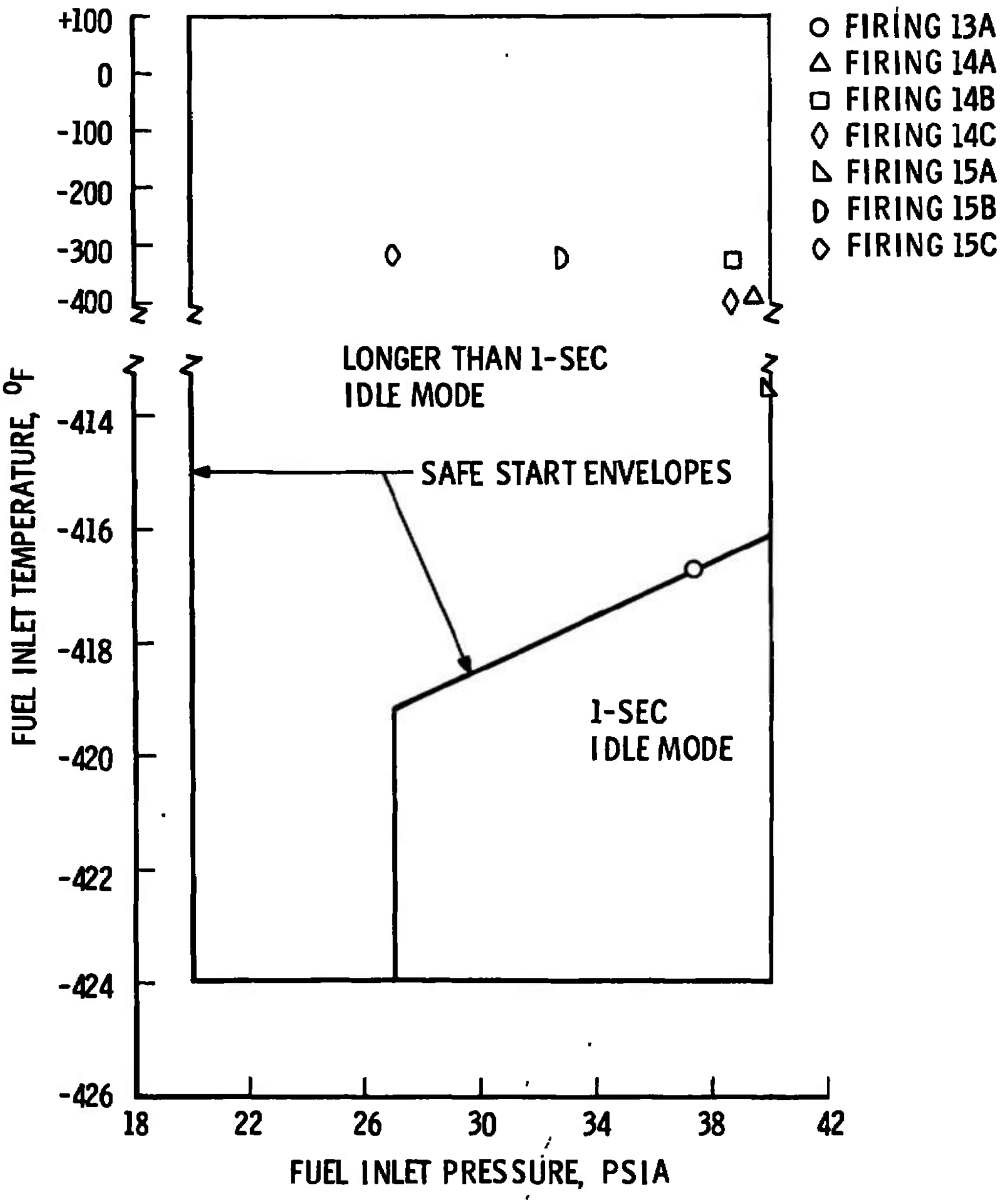


a. Start Sequence



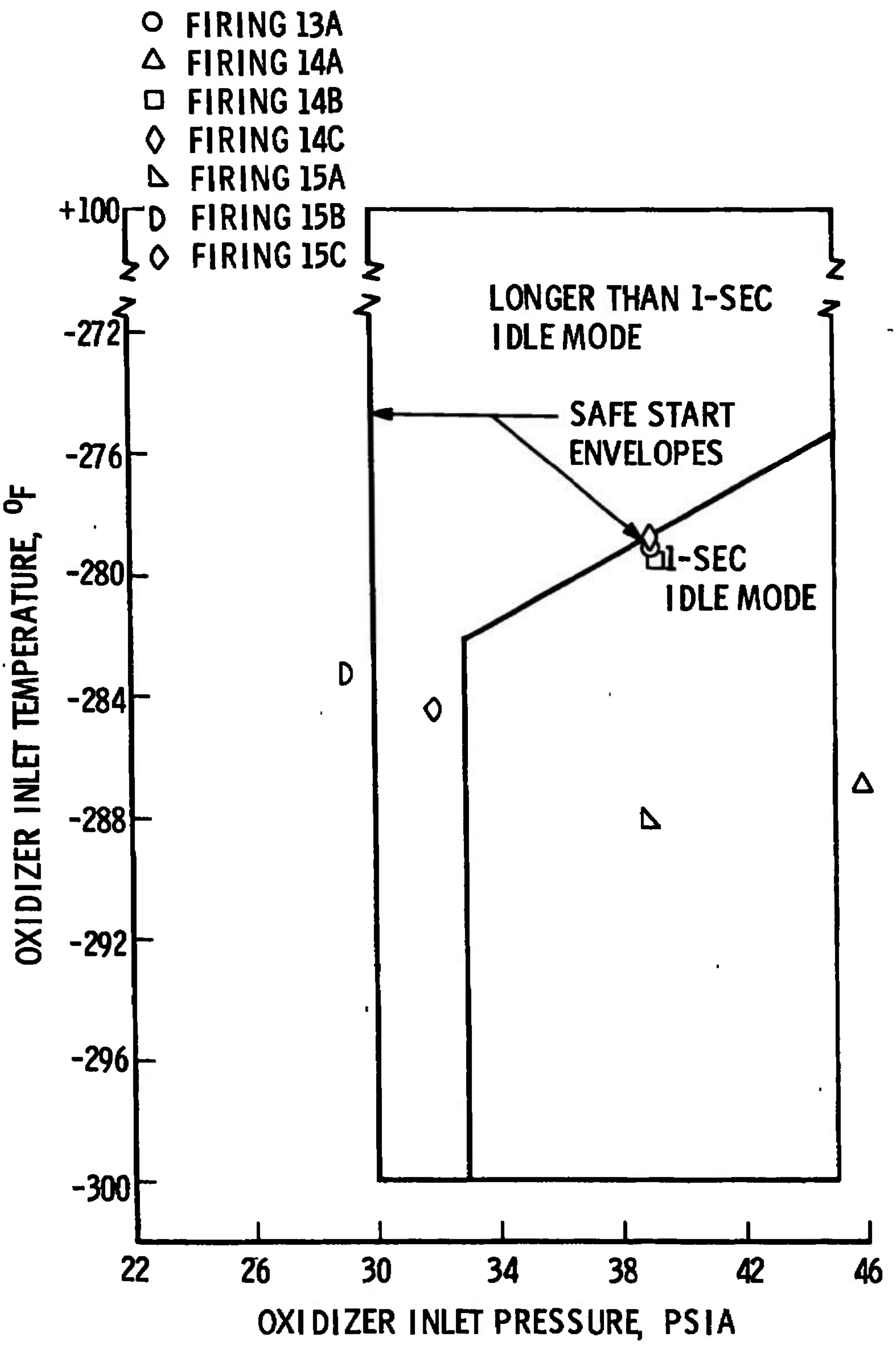
b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence

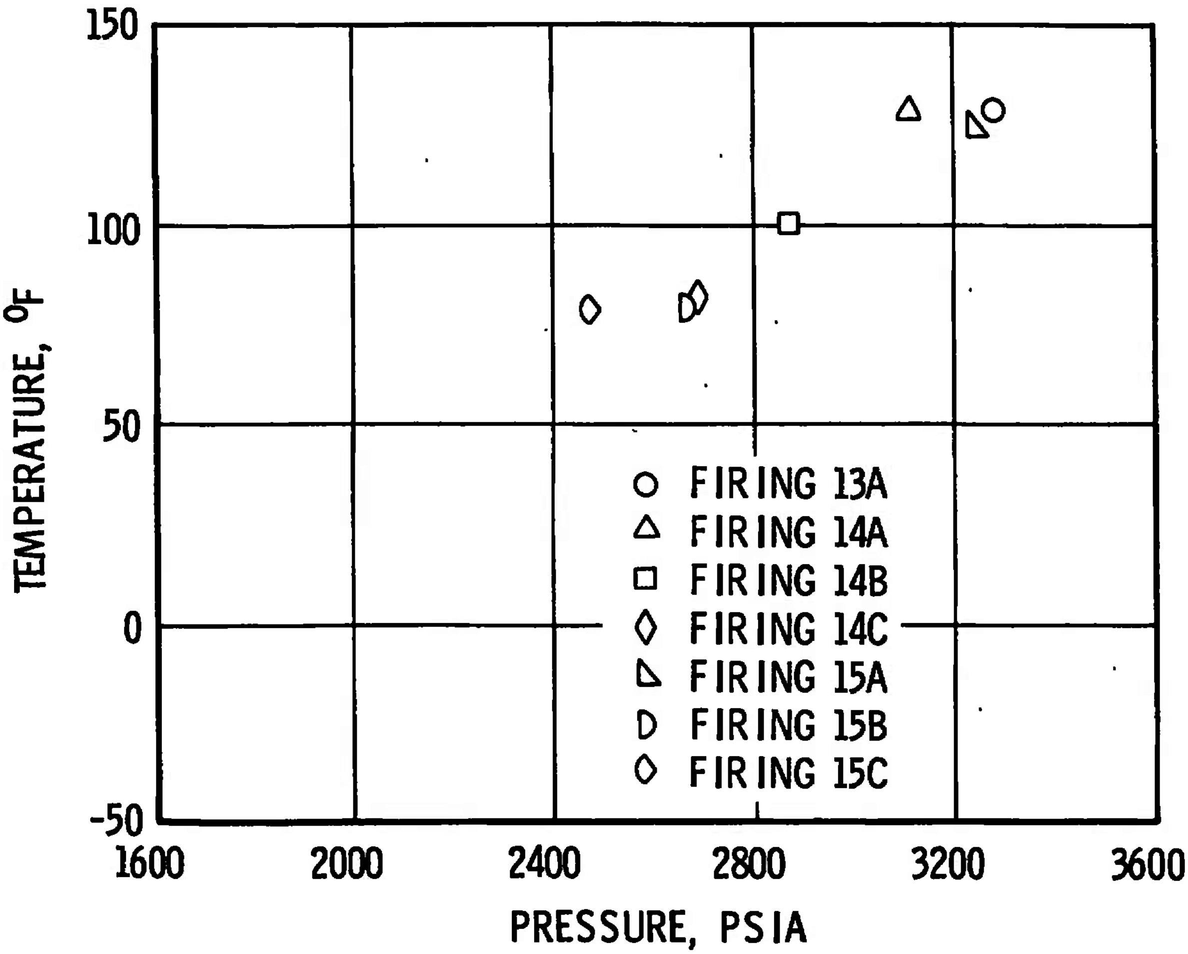


a. Fuel Pump

Fig. 8 Engine Start Conditions for Propellant Pump Inlets and Helium Tank



b. Oxidizer Pump
Fig. 8 Continued



c. Helium Tank
Fig. 8 Concluded

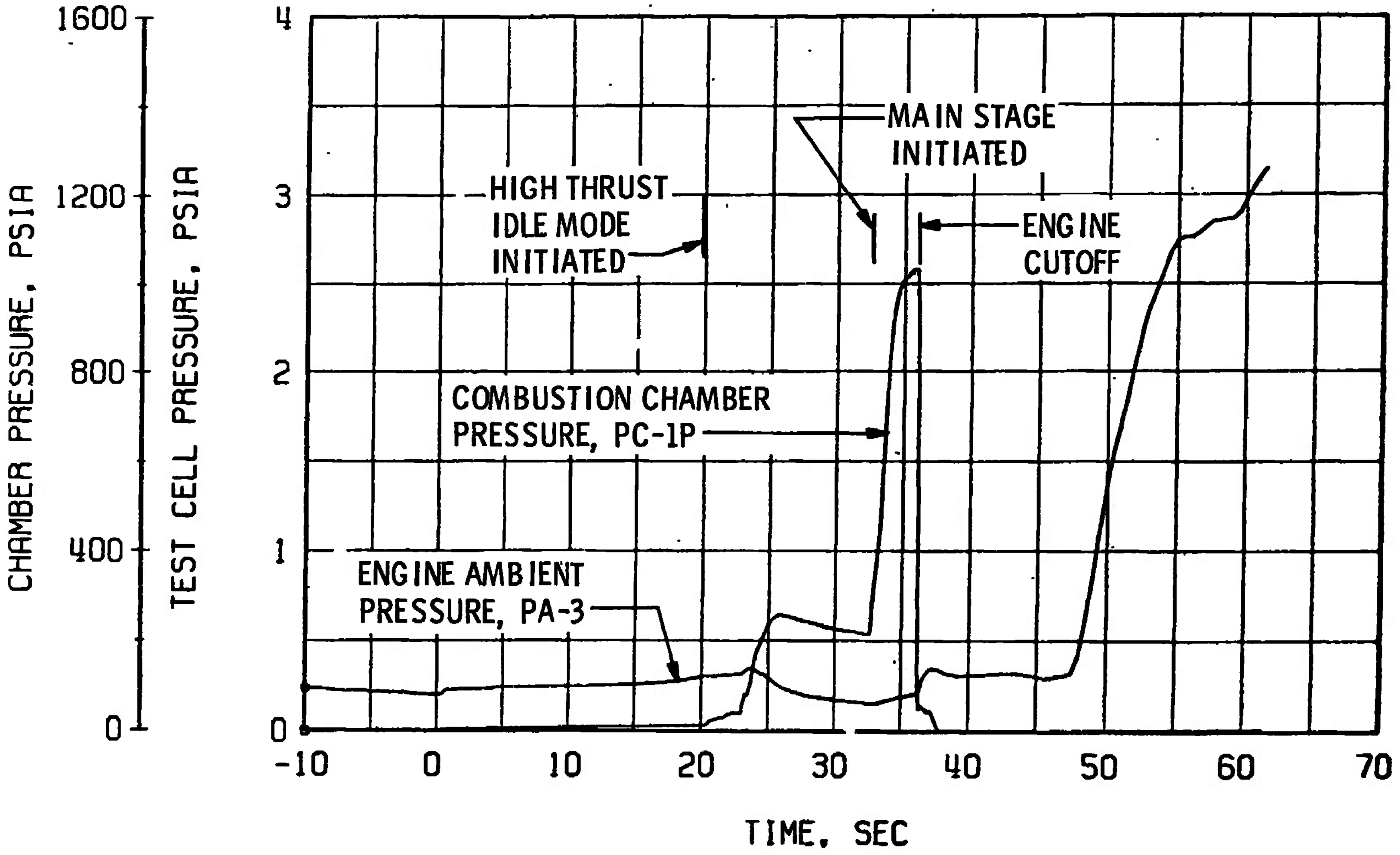


Fig. 9 Engine Ambient and Combustion Chamber Pressures, Firing 13A

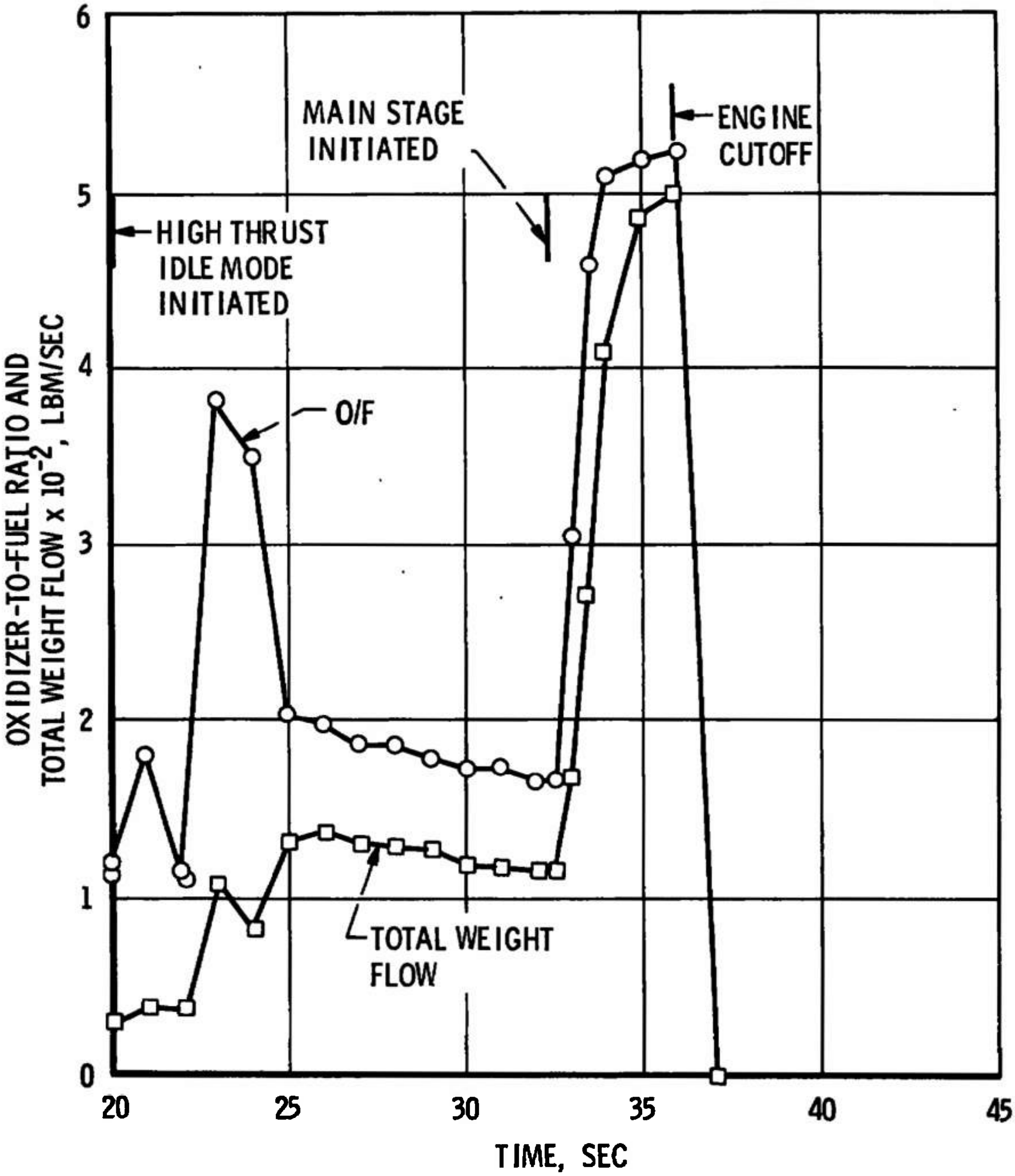
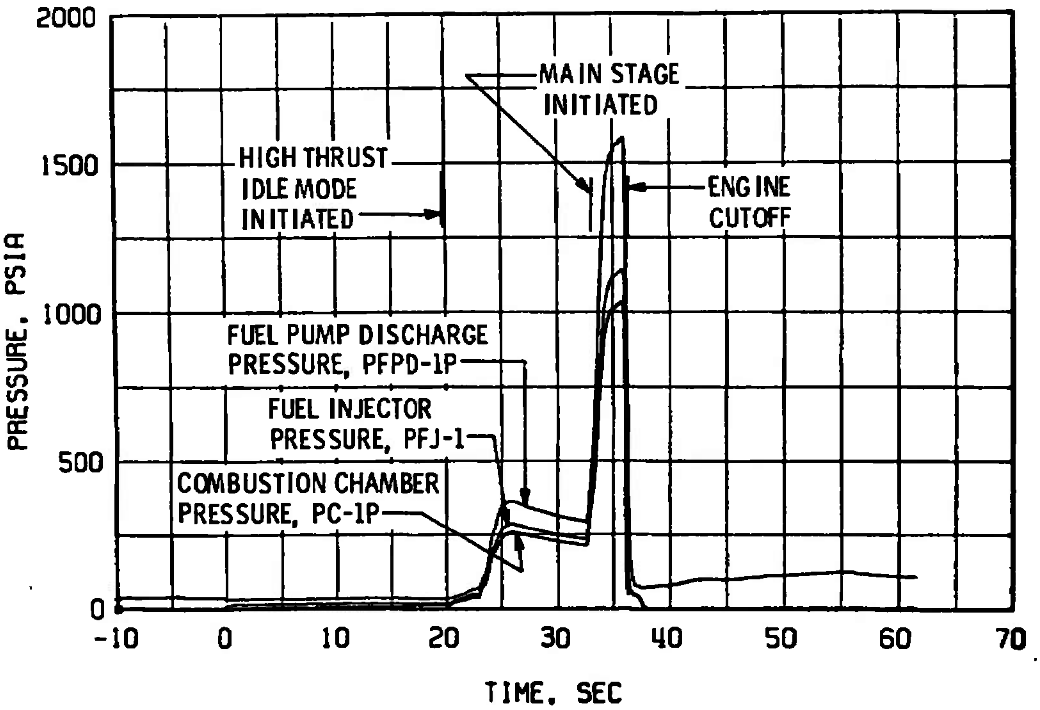
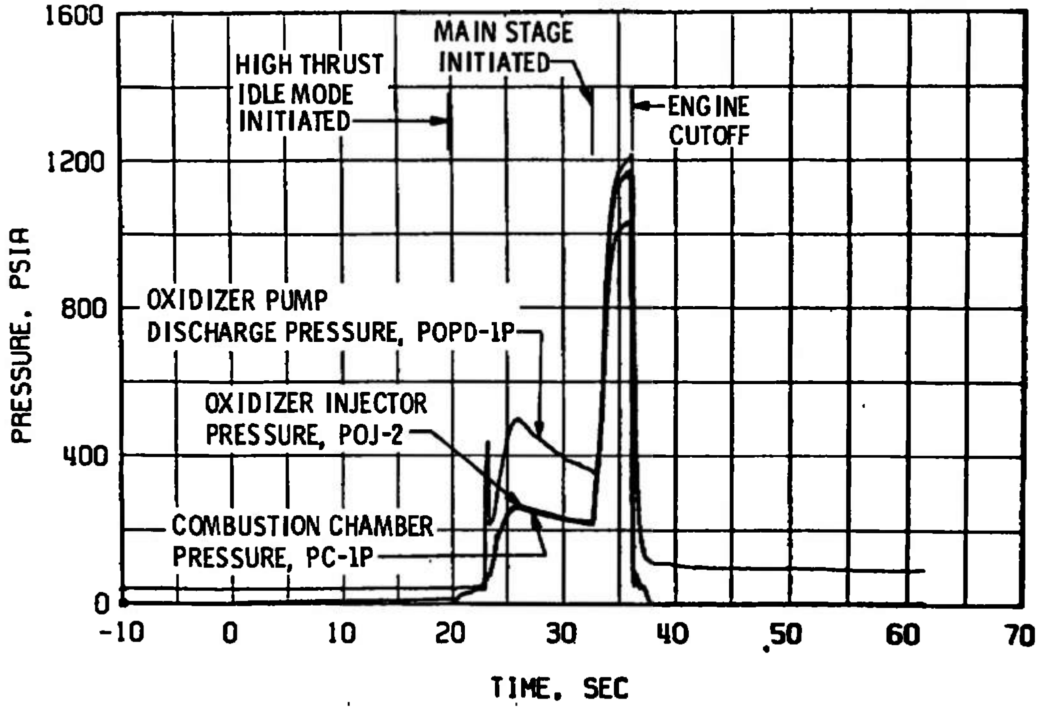


Fig. 10 Engine Total Propellant Flow Rate and Injector Mixture Ratio, Firing 13A



a. Fuel



b. Oxidizer

Fig. 11 Propellant Feed System Performance, Firing 13A

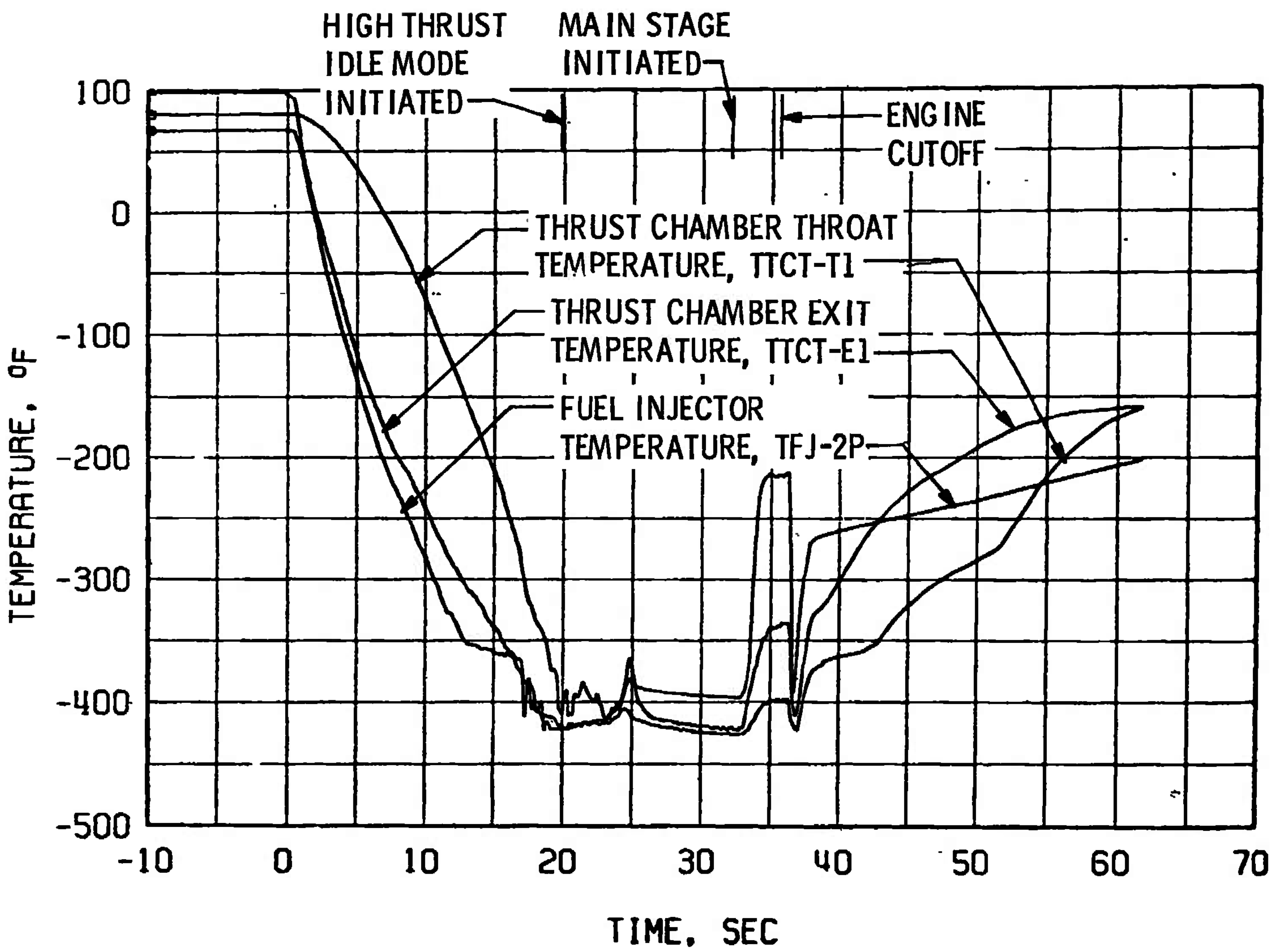


Fig. 12 Thrust Chamber and Injector Childown Characteristics, Firing 13A

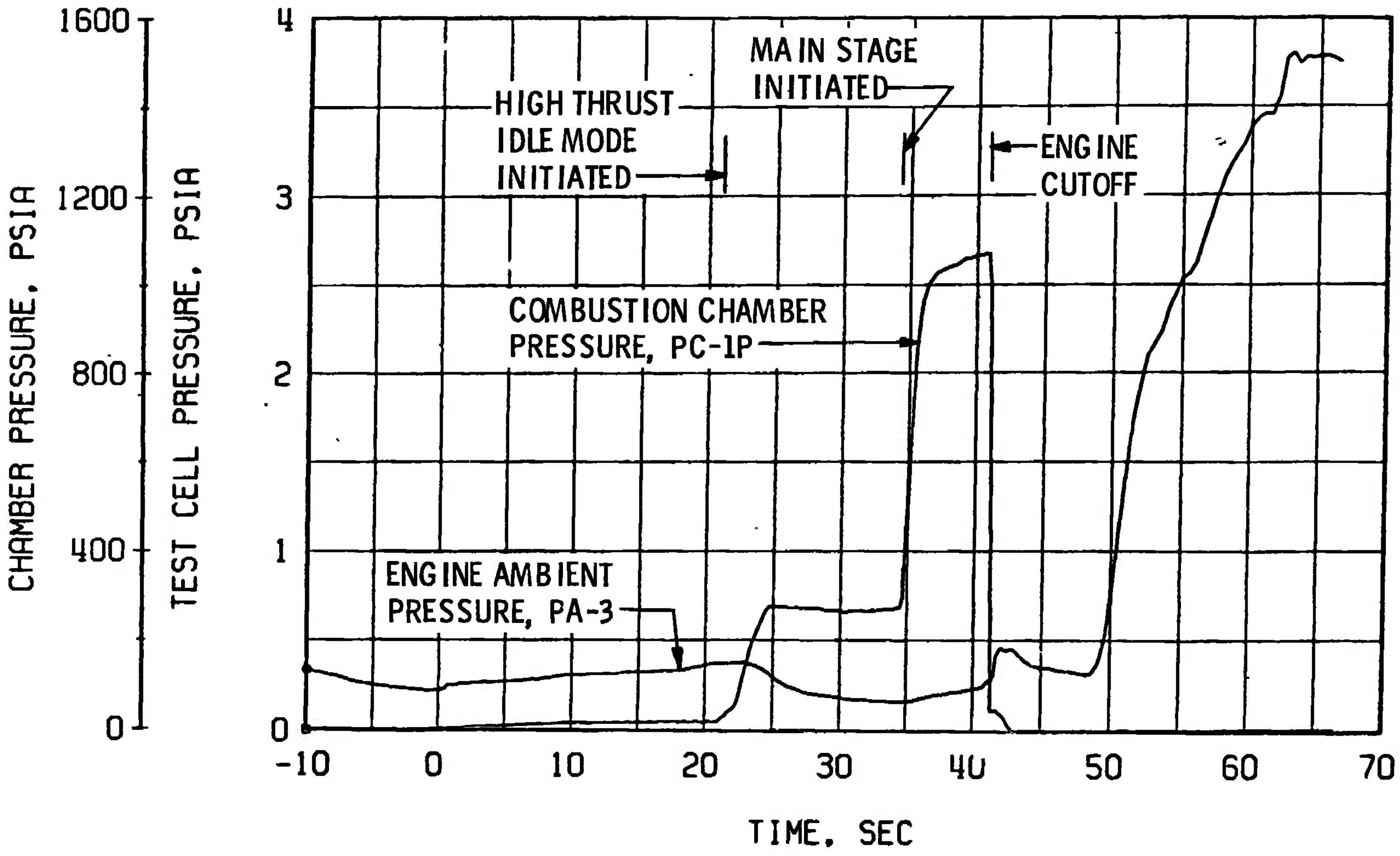


Fig. 13 Engine Ambient and Combustion Chamber Pressures, Firing 14A

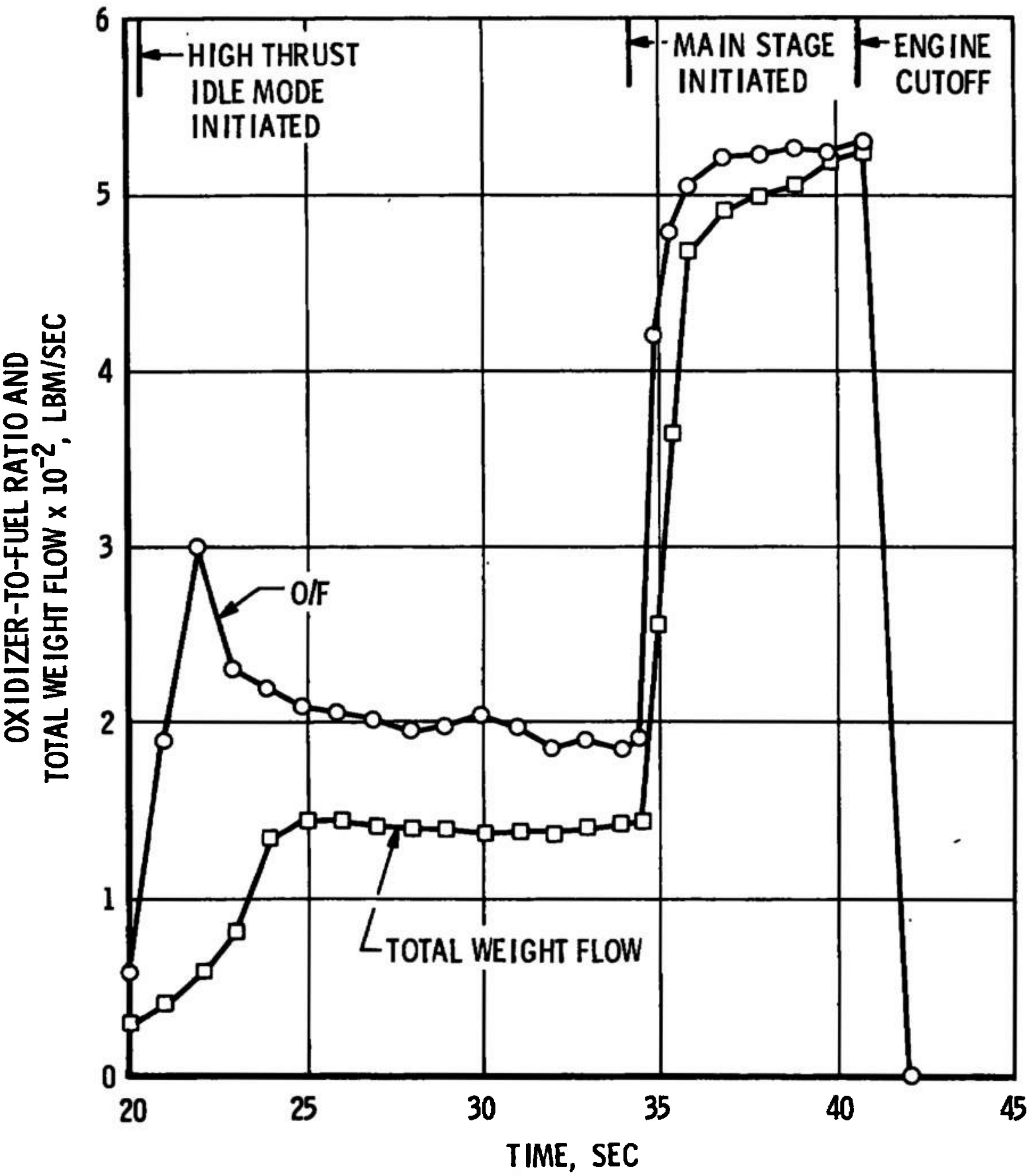
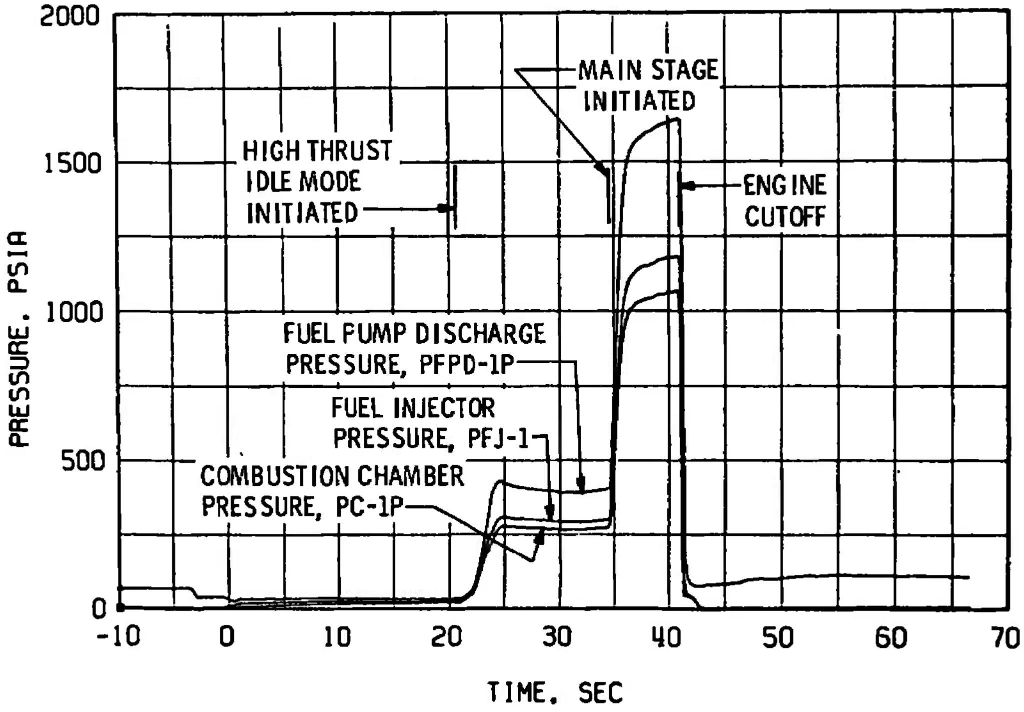
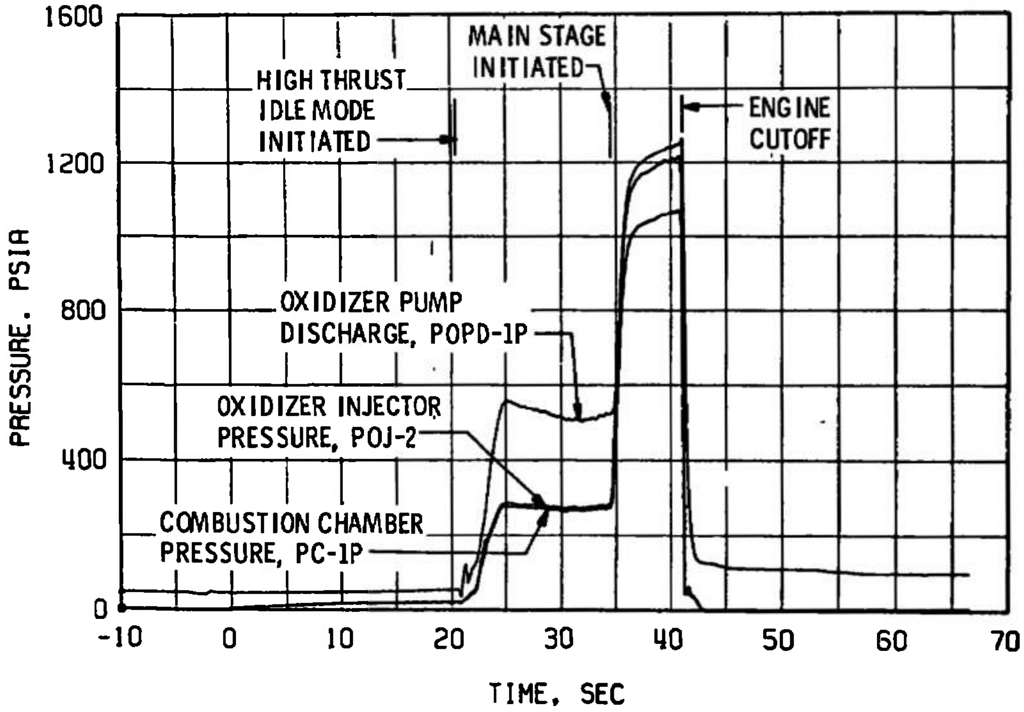


Fig. 14 Engine Total Propellant Flow Rate and Injector Mixture Ratio, Firing 14A



a. Fuel



b. Oxidizer

Fig. 15 Propellant Feed System Performance, Firing 14A

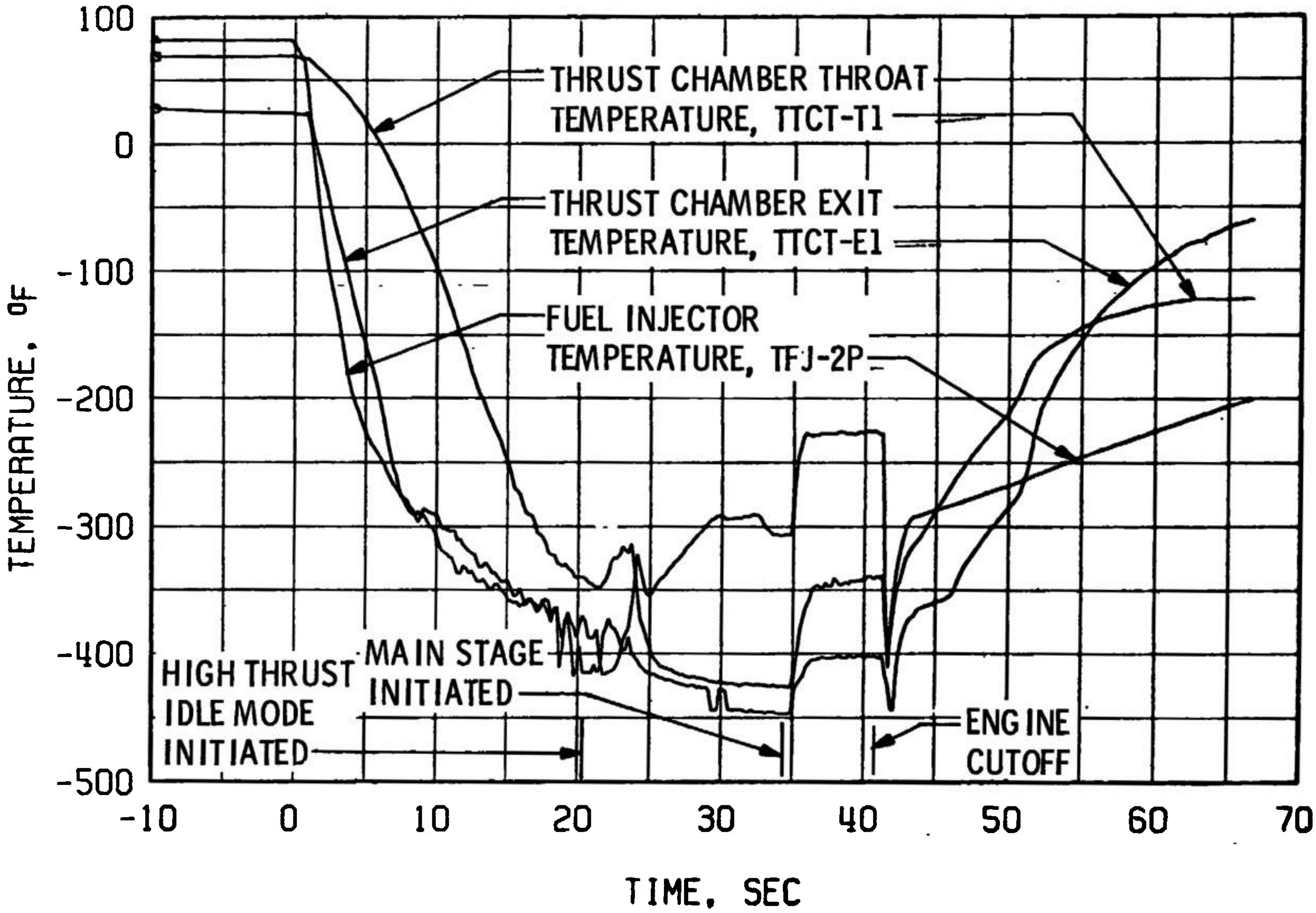


Fig. 16 Thrust Chamber and Injector Chilldown Characteristics, Firing 14A

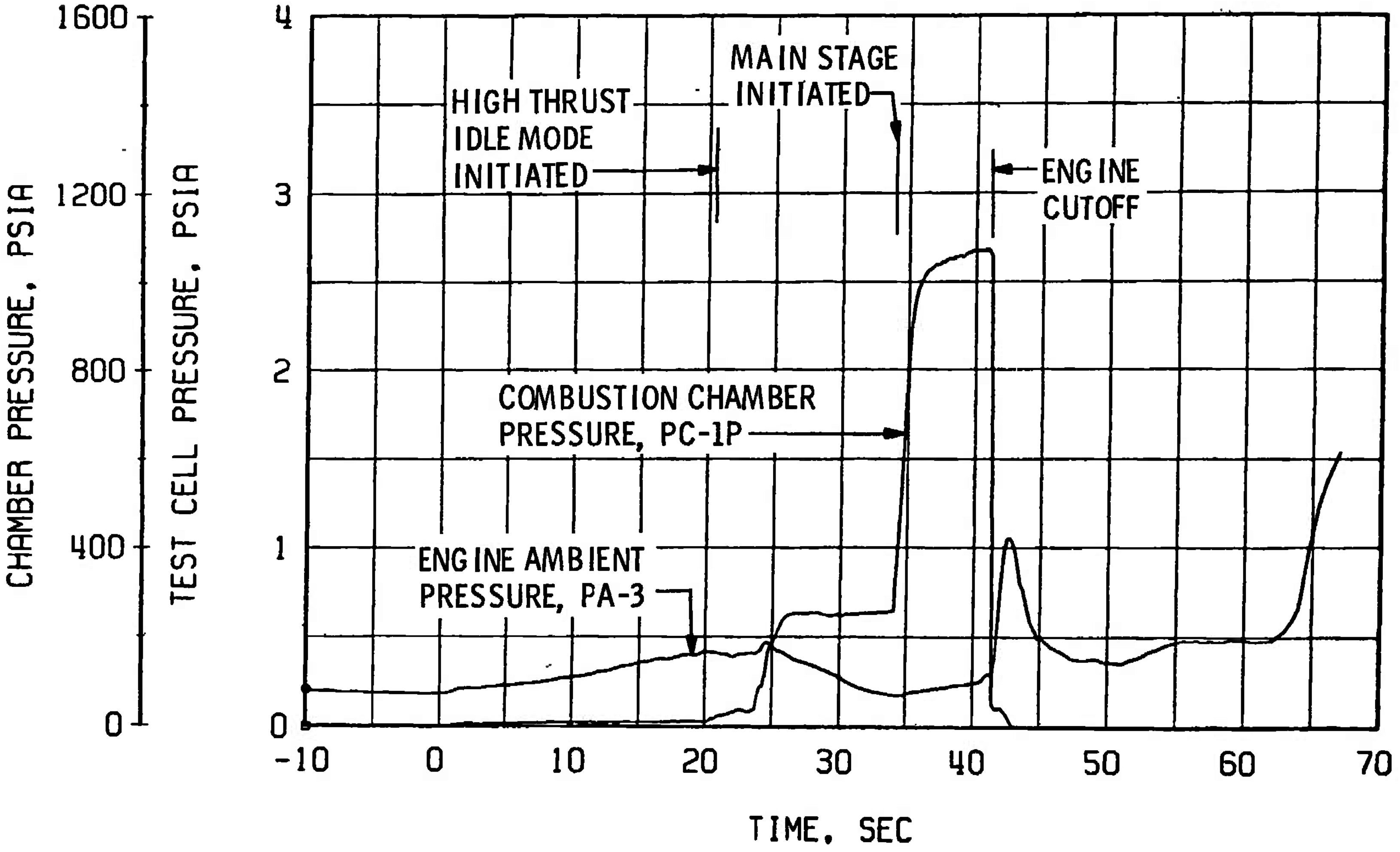


Fig. 17 Engine Ambient and Combustion Chamber Pressures, Firing 14B

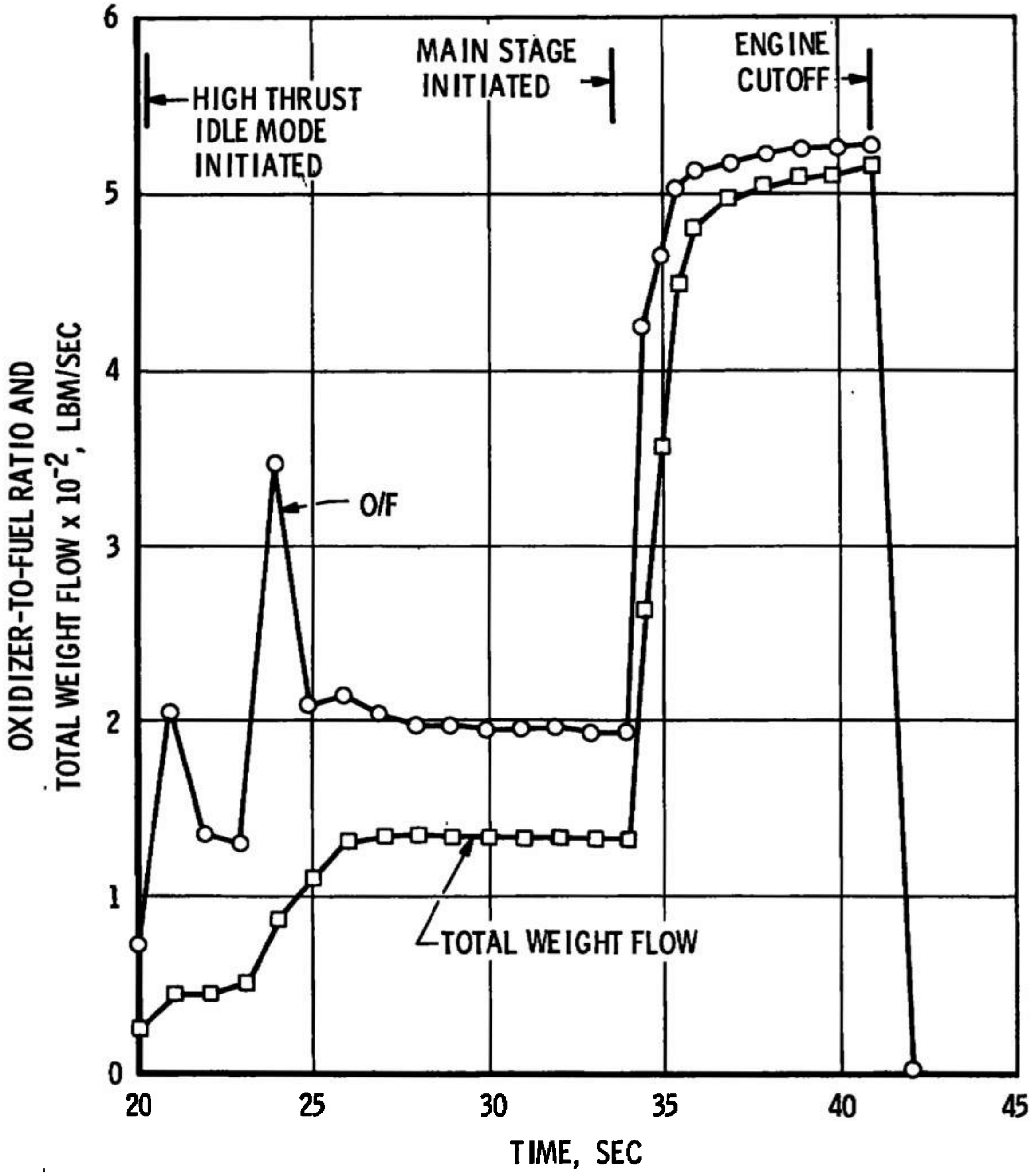
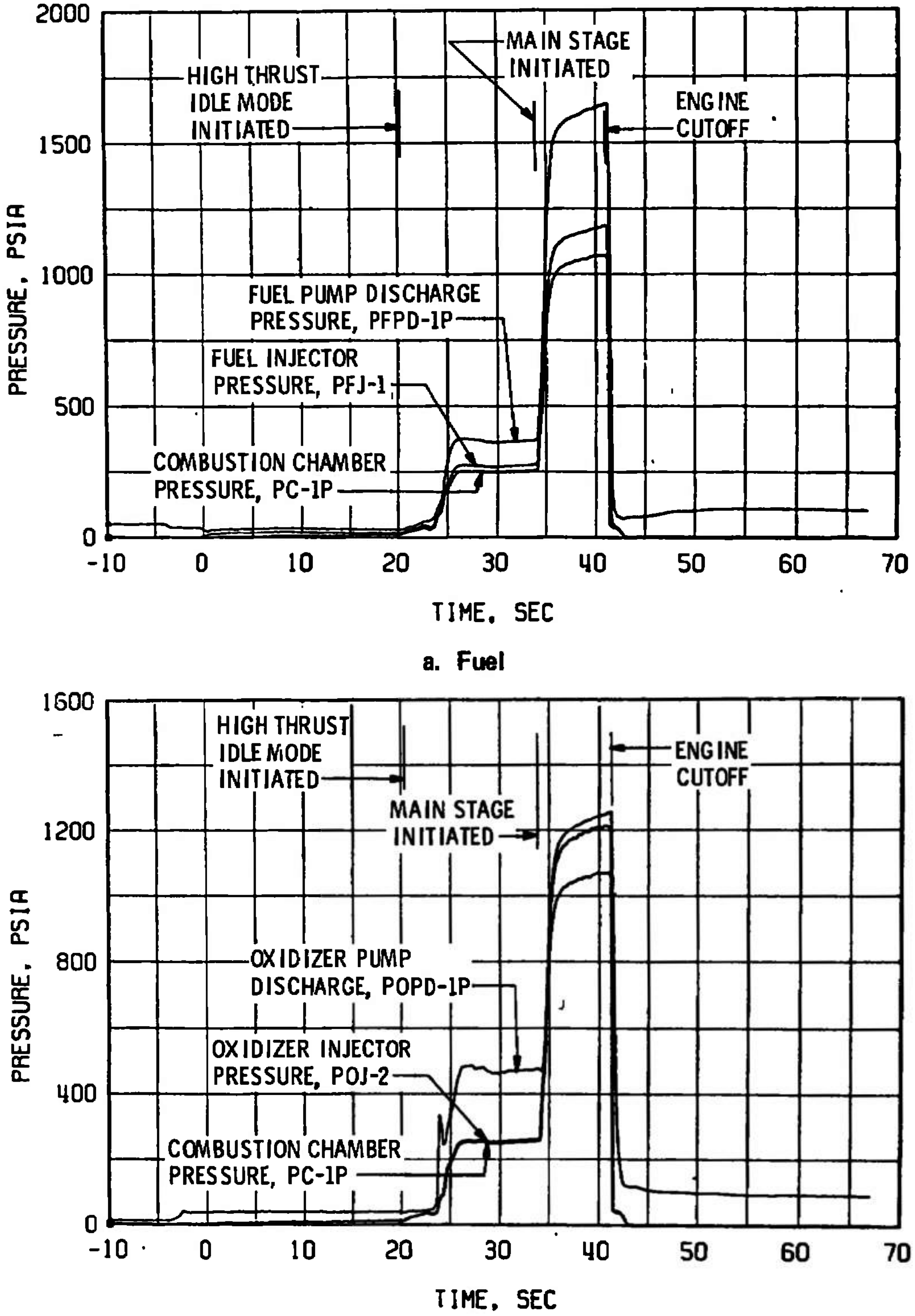


Fig. 18 Engine Total Propellant Flow Rate and Injector Mixture Ratio, Firing 14B



a. Fuel

b. Oxidizer

Fig. 19 Propellant Feed System Performance, Firing 14B

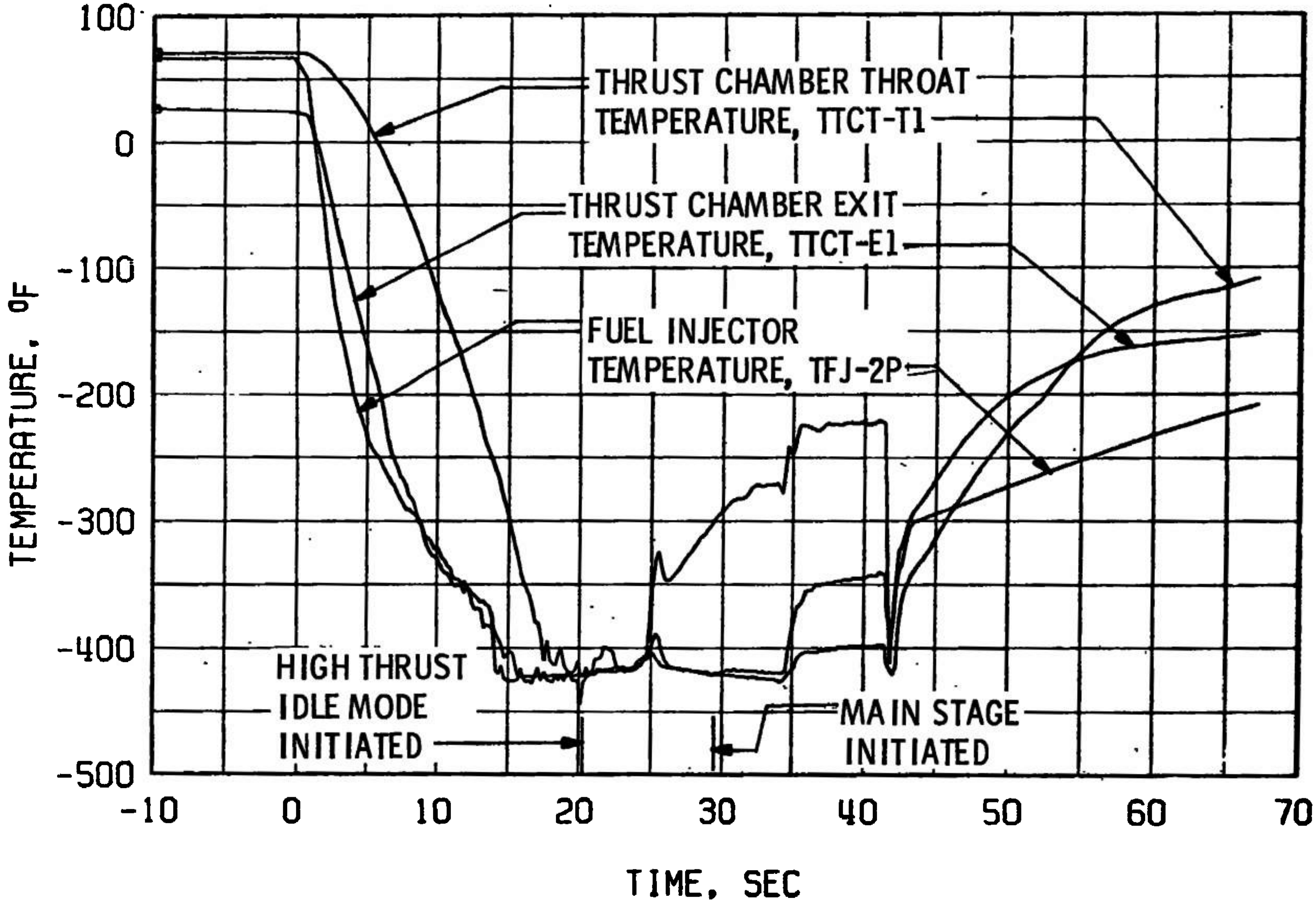


Fig. 20 Thrust Chamber and Injector Chilldown Characteristics, Firing 14B

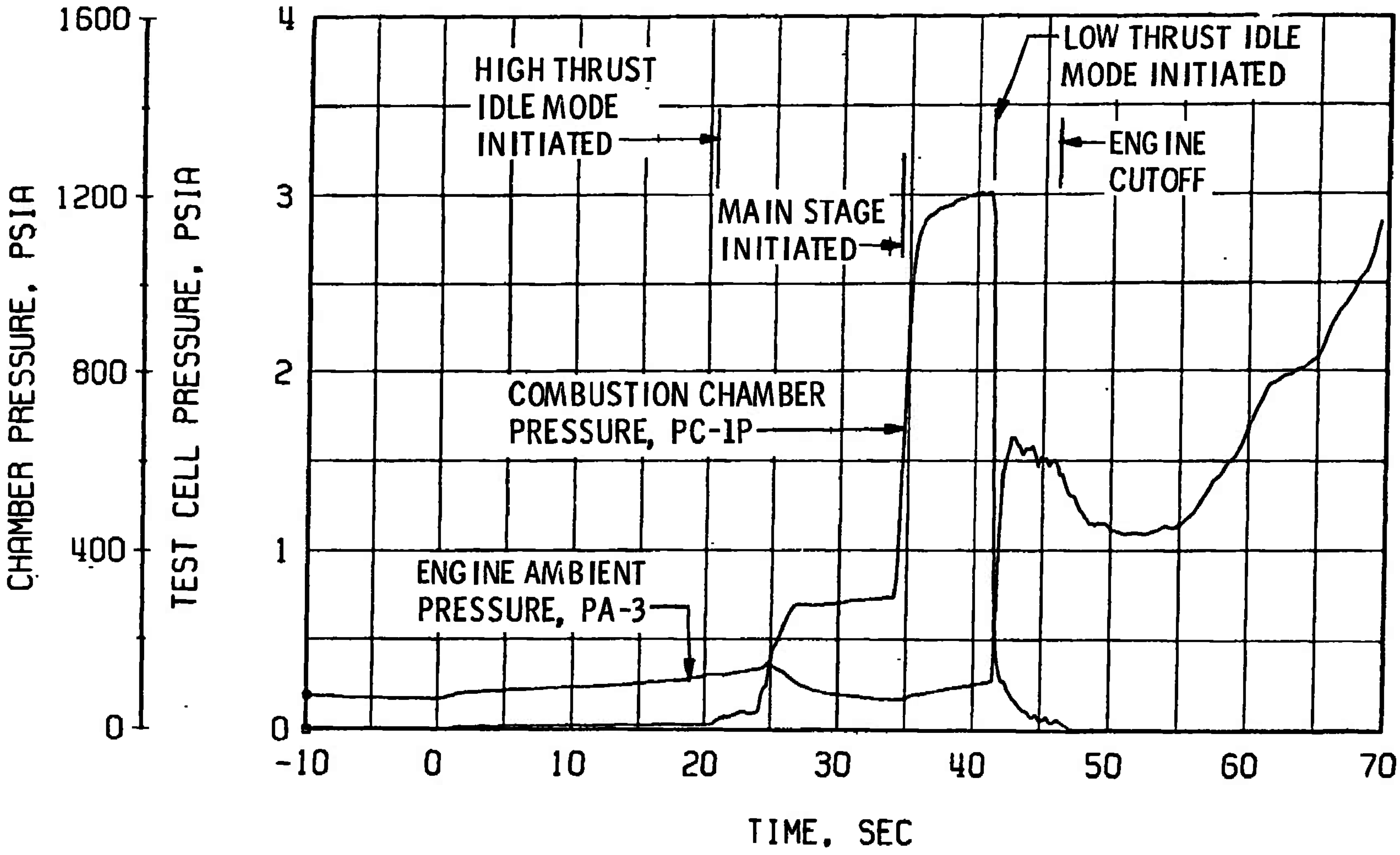


Fig. 21 Engine Ambient and Combustion Chamber Pressures, Firing 14C

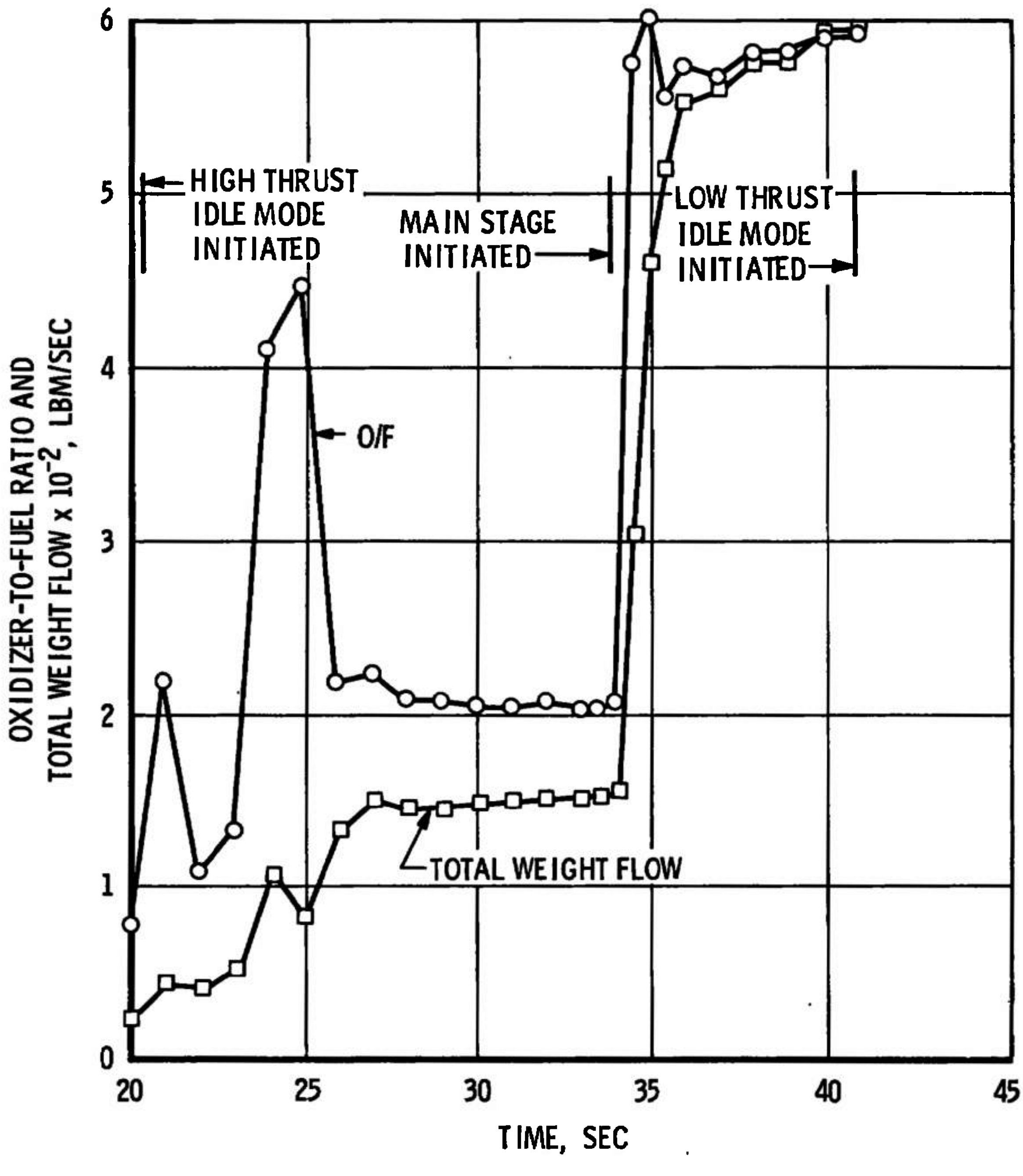
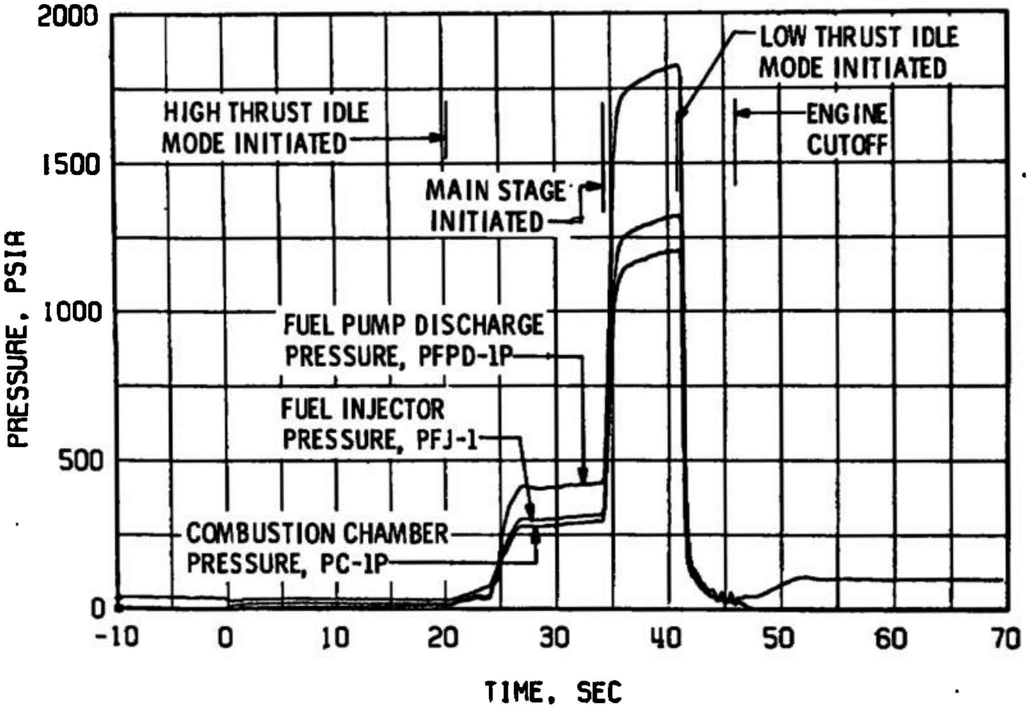
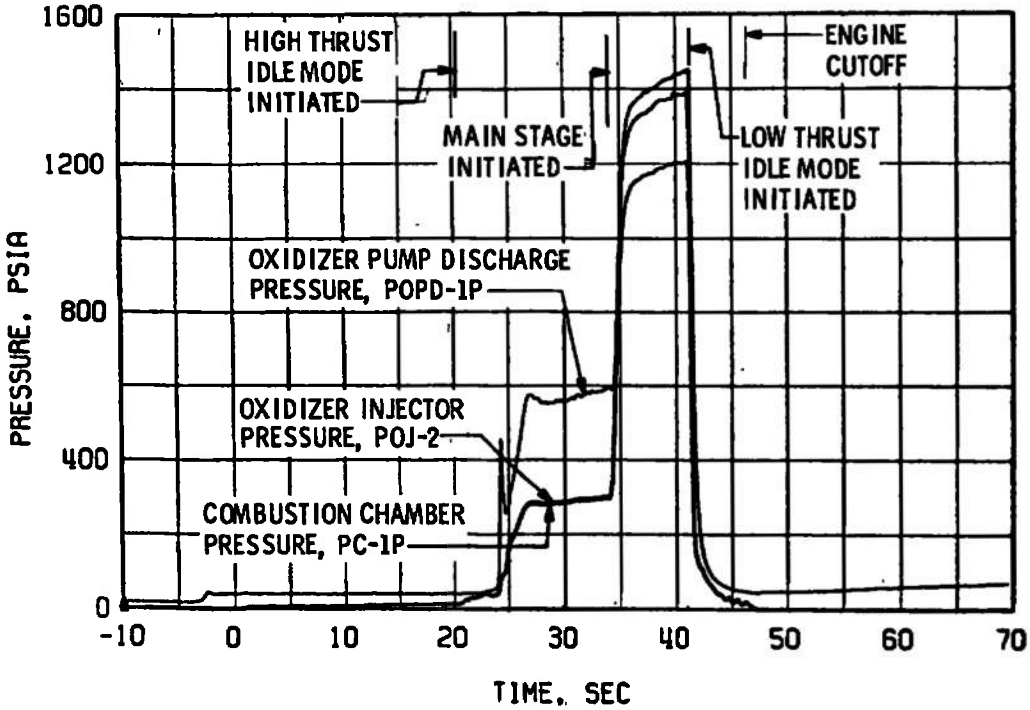


Fig. 22 Engine Total Propellant Flow Rate and Injector Mixture Ratio, Firing 14C



a. Fuel



b. Oxidizer

Fig. 23 Propellant Feed System Performance, Firing 14C

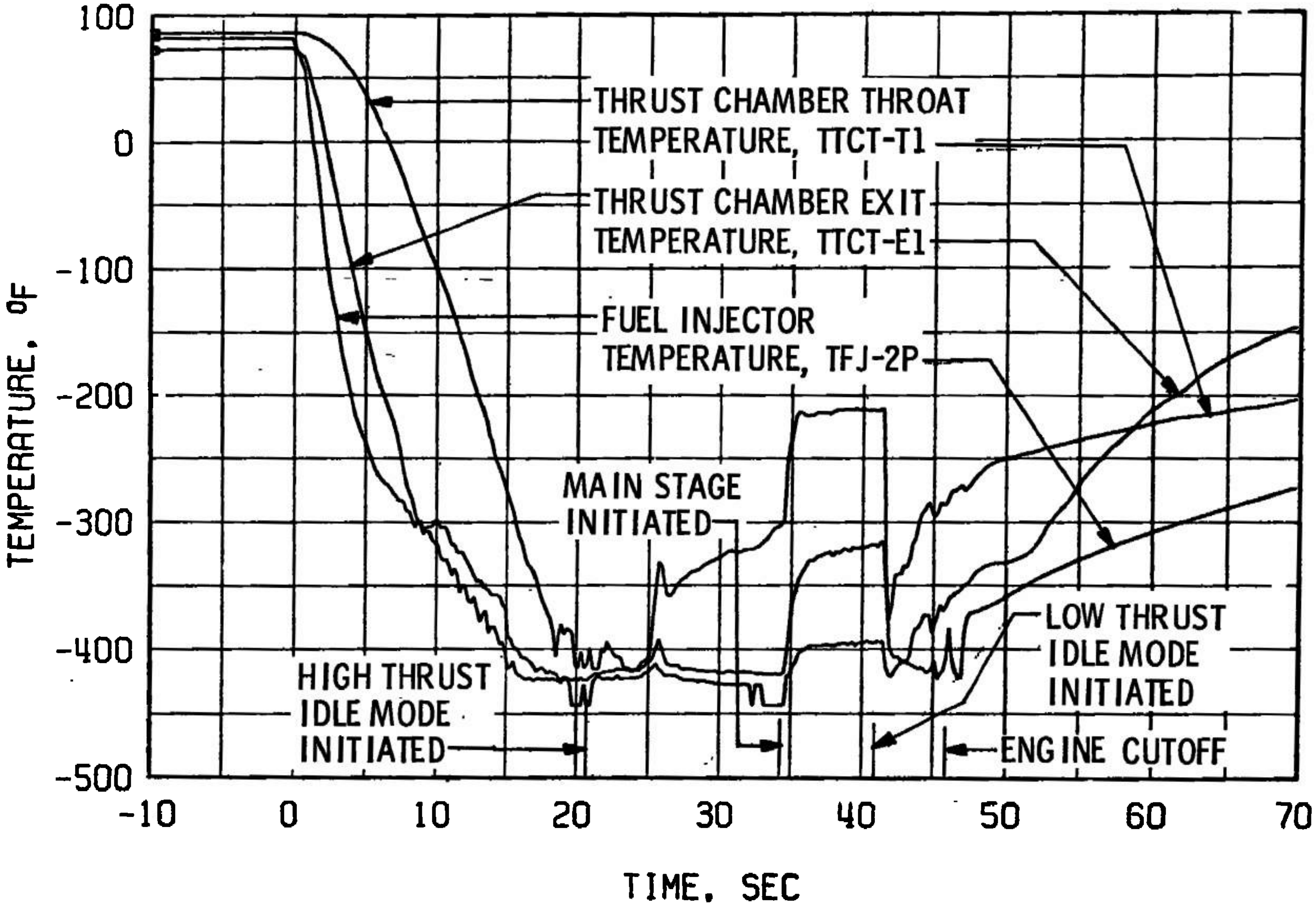


Fig. 24 Thrust Chamber and Injector Chilldown Characteristics, Firing 14C

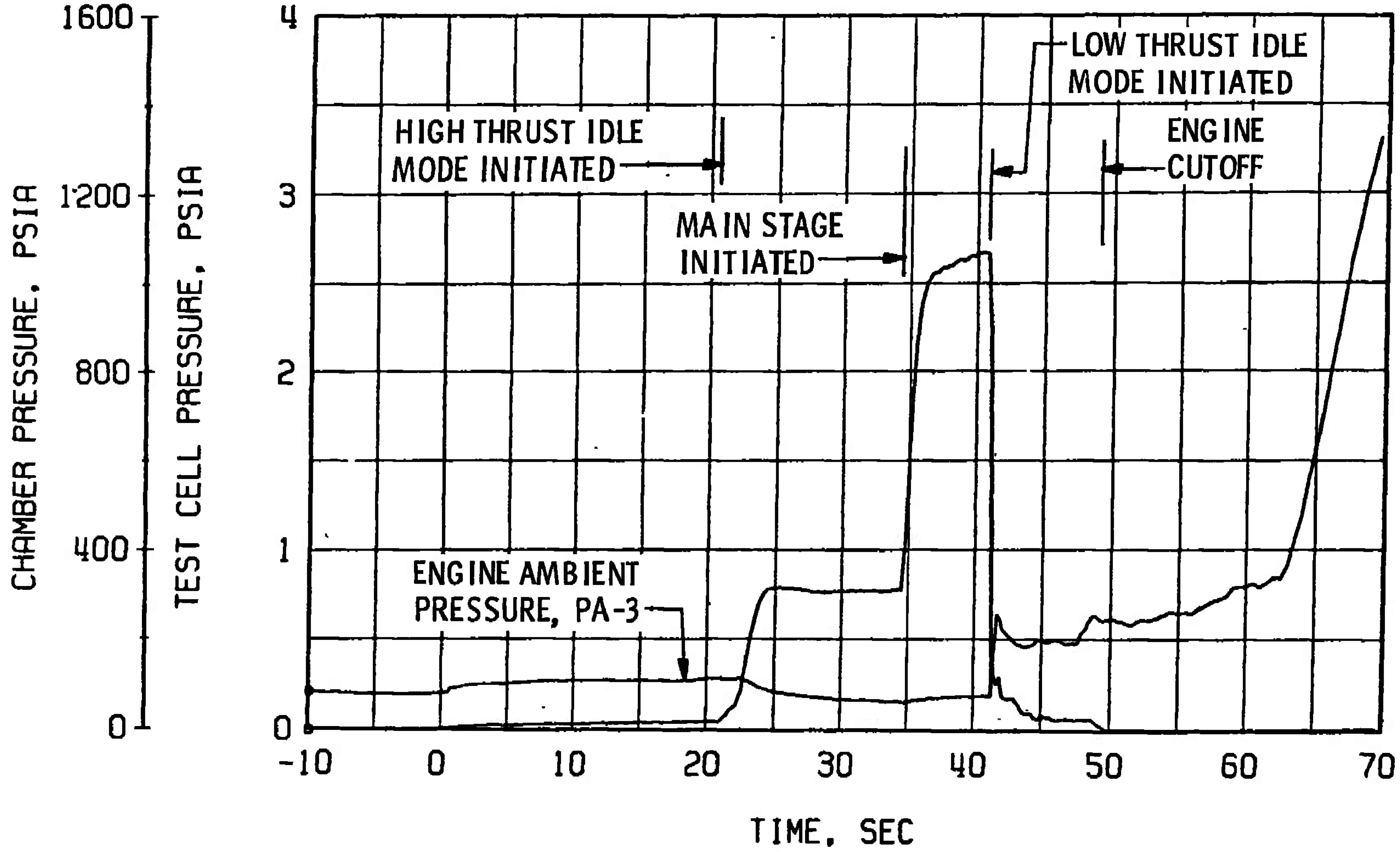


Fig. 25 Engine Ambient and Combustion Chamber Pressures, Firing 15A

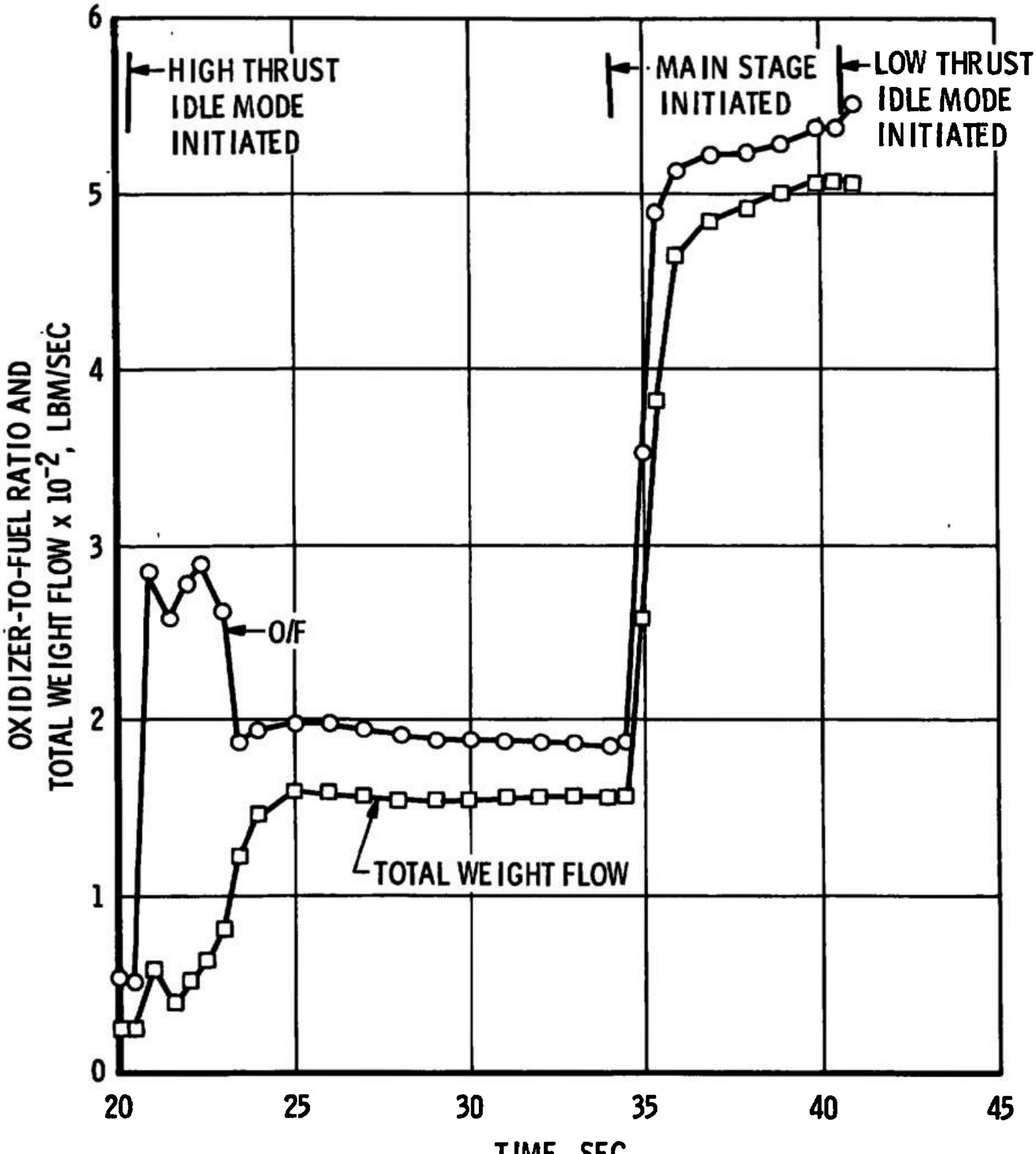
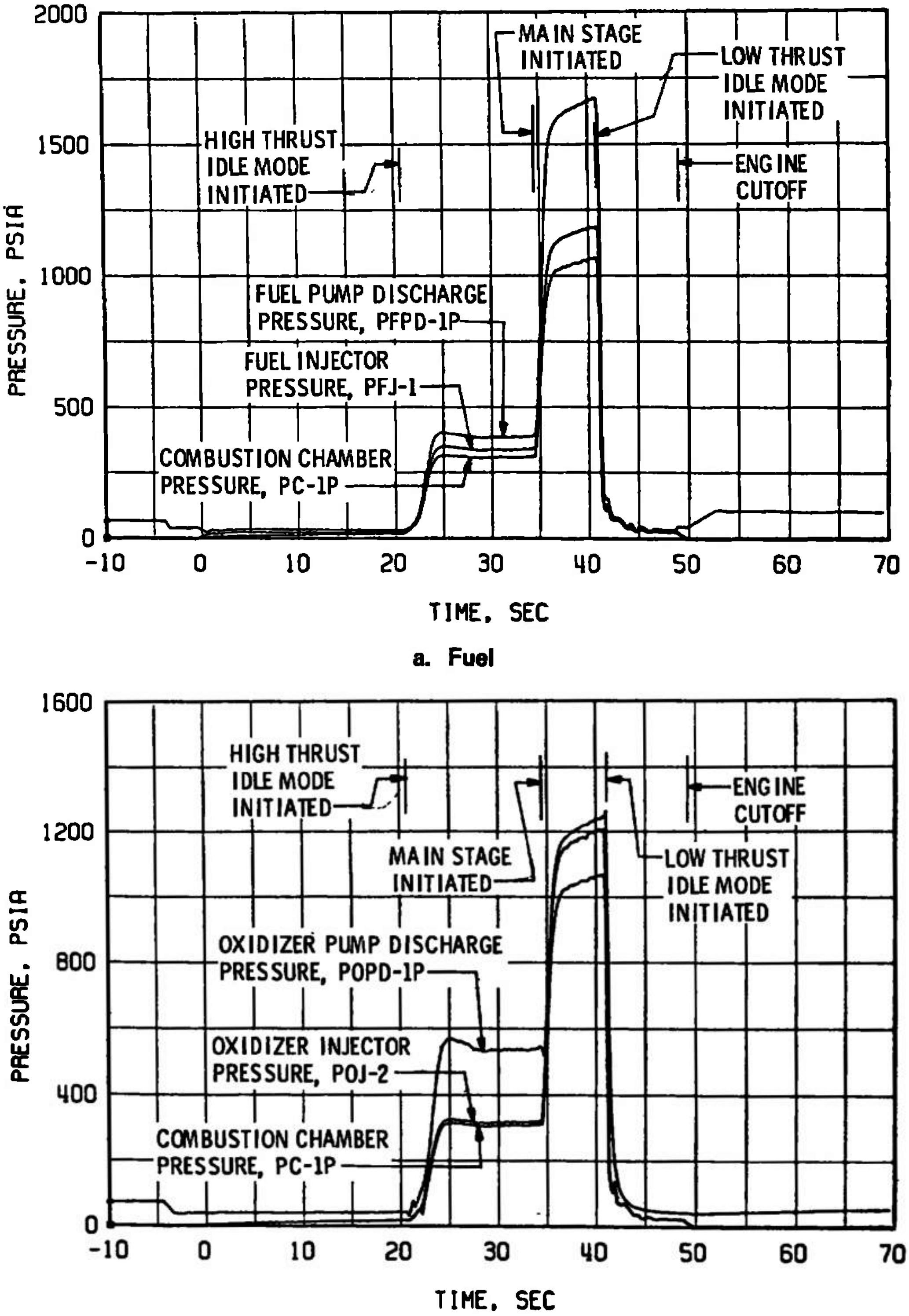


Fig. 26 Engine Total Propellant Flow Rate and Injector Mixture Ratio, Firing 15A



a. Fuel

b. Oxidizer

Fig. 27 Propellant Feed System Performance, Firing 15A

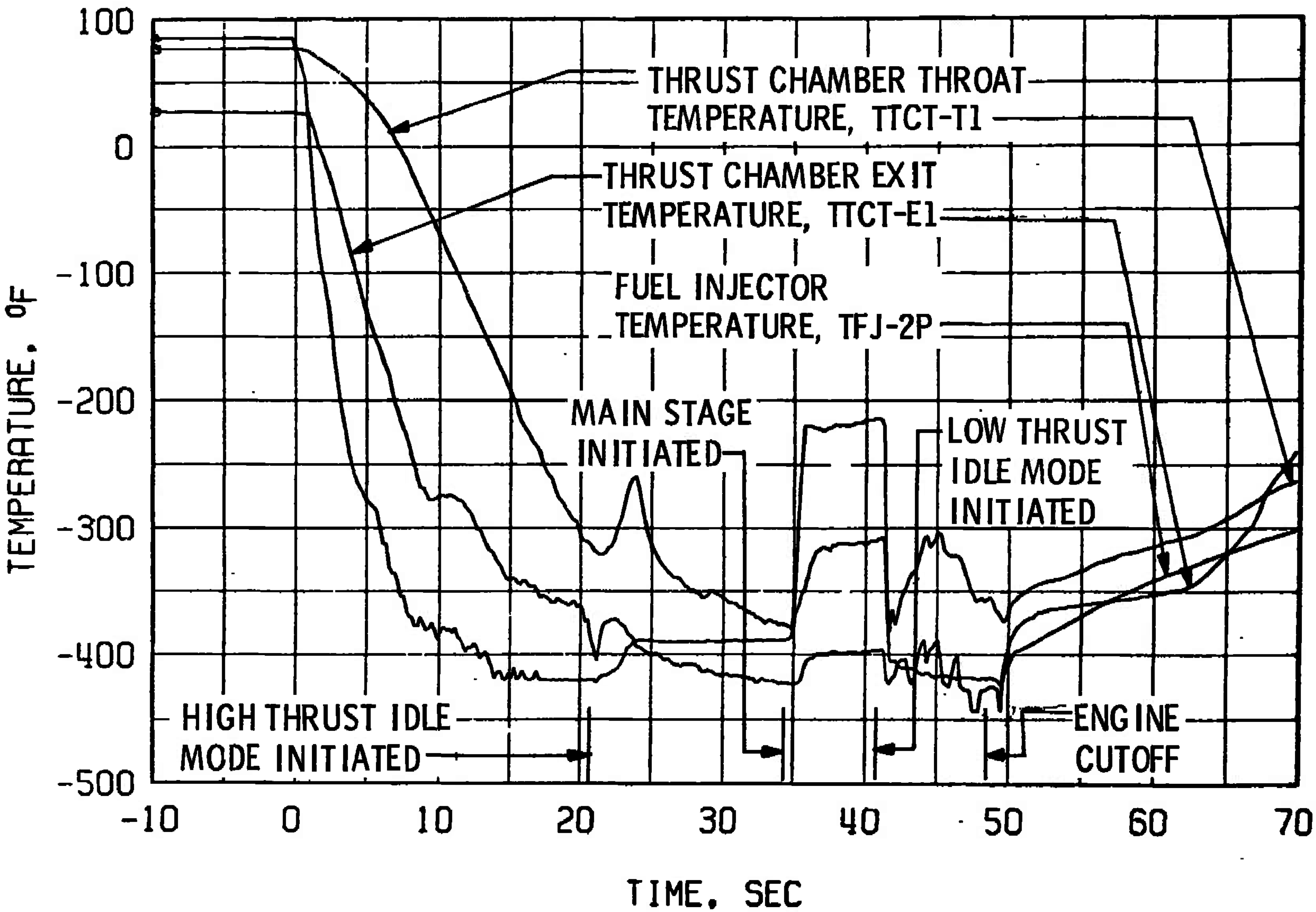


Fig. 28 Thrust Chamber and Injector Chilldown Characteristics, Firing 15A

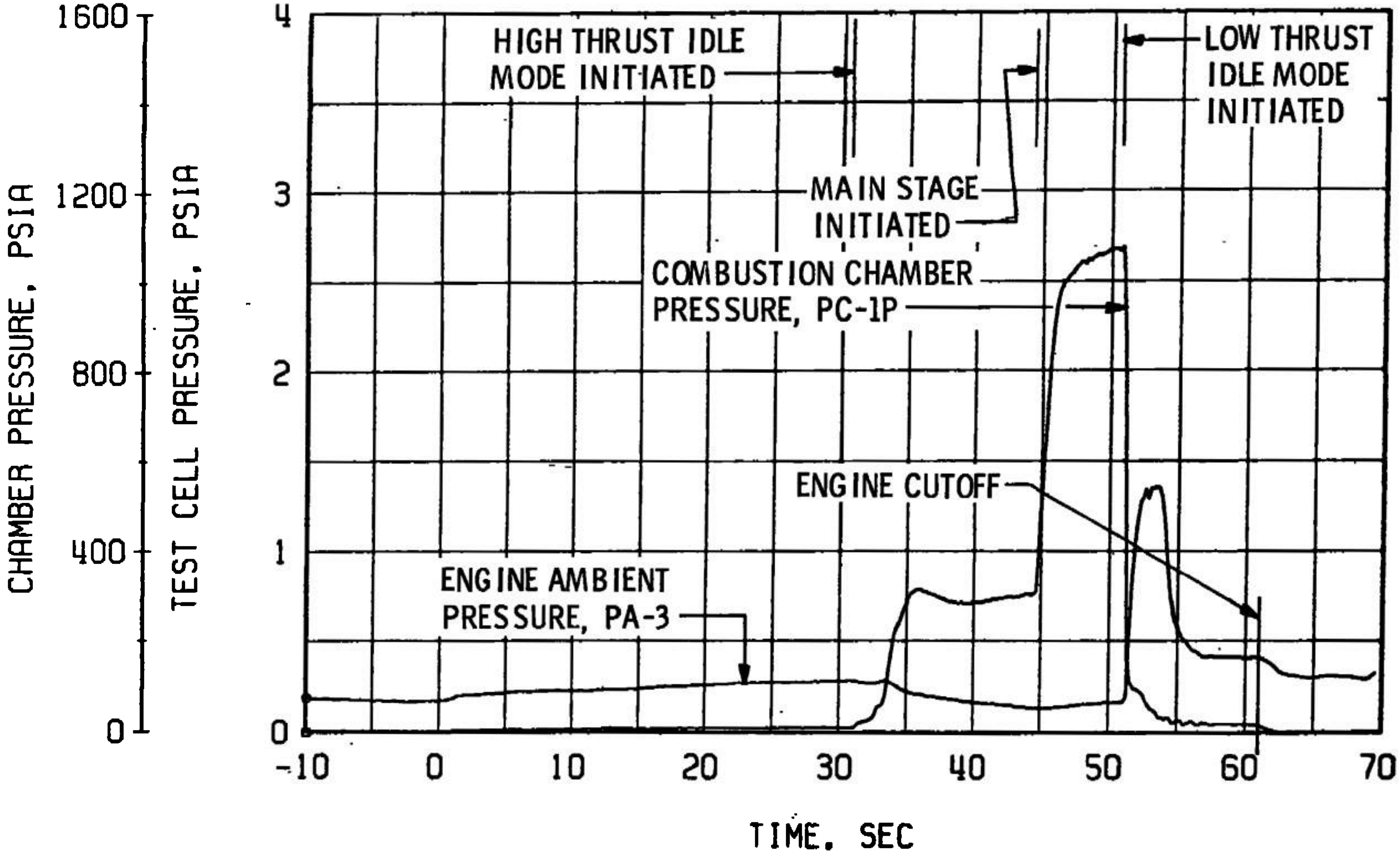


Fig. 29 Engine Ambient and Combustion Chamber Pressures, Firing 15B

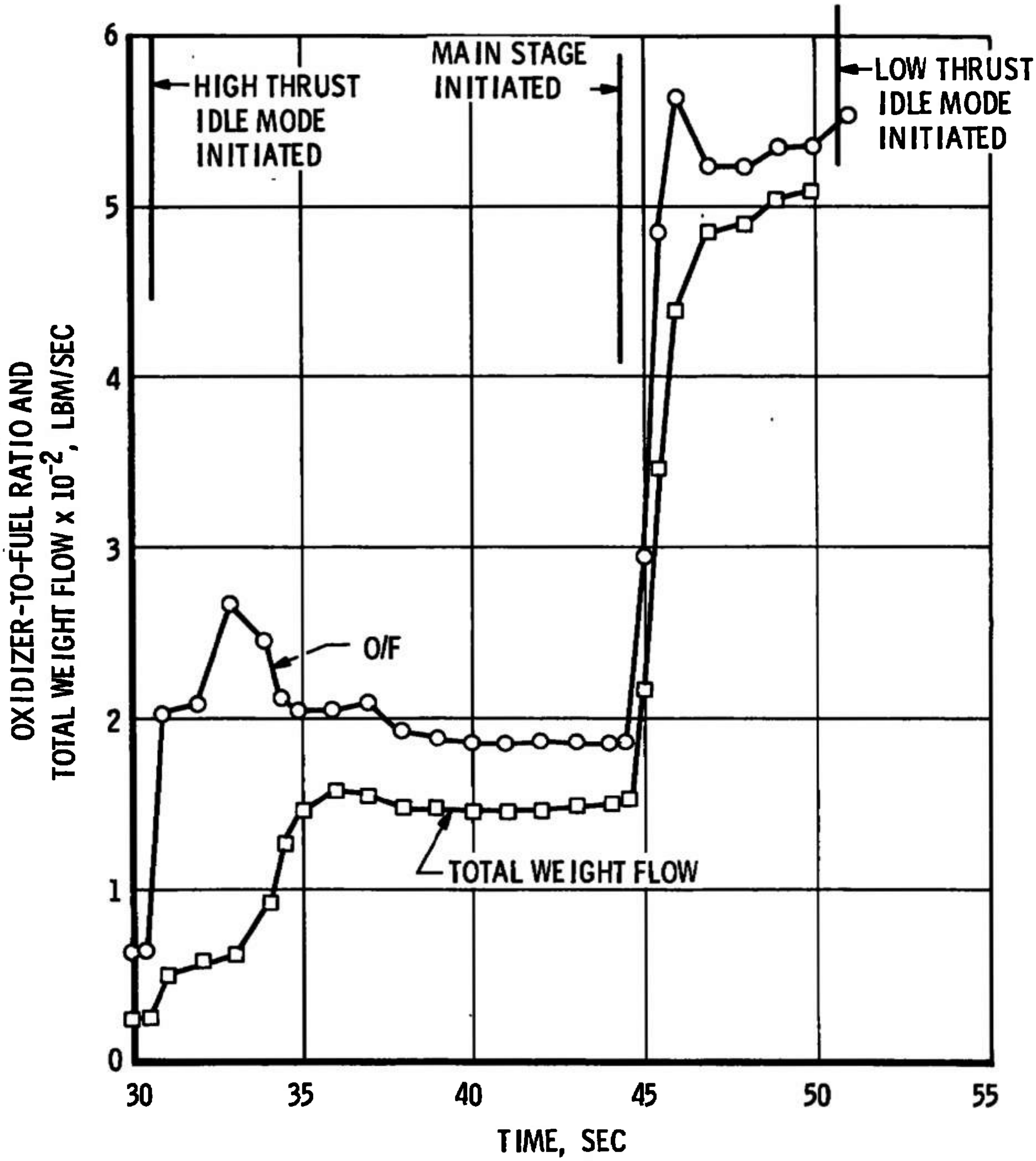
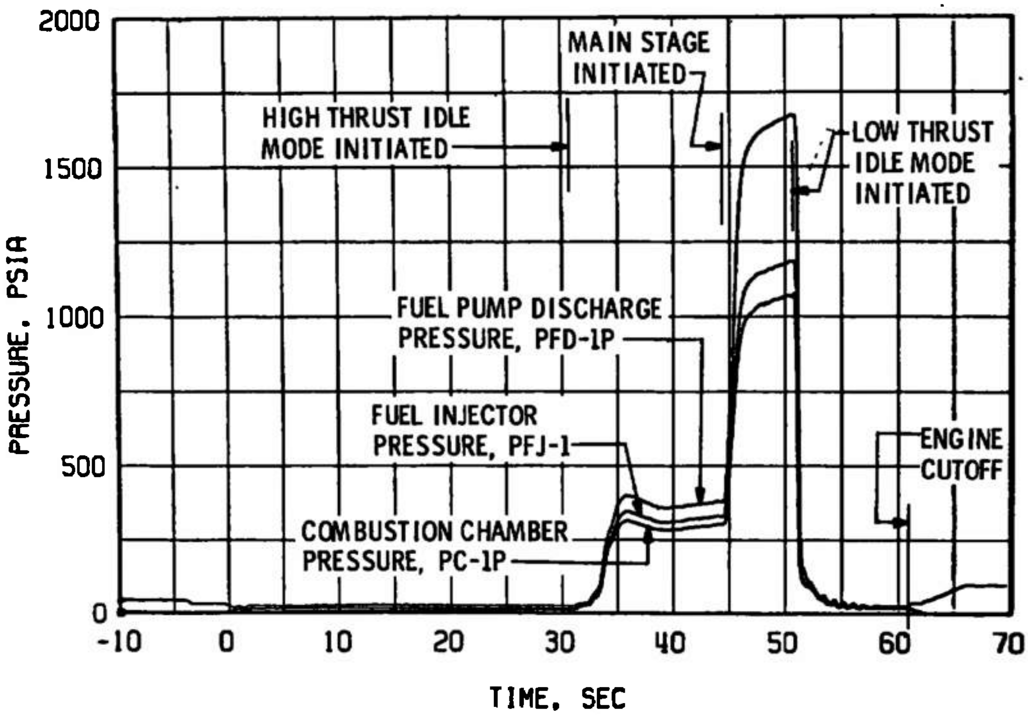
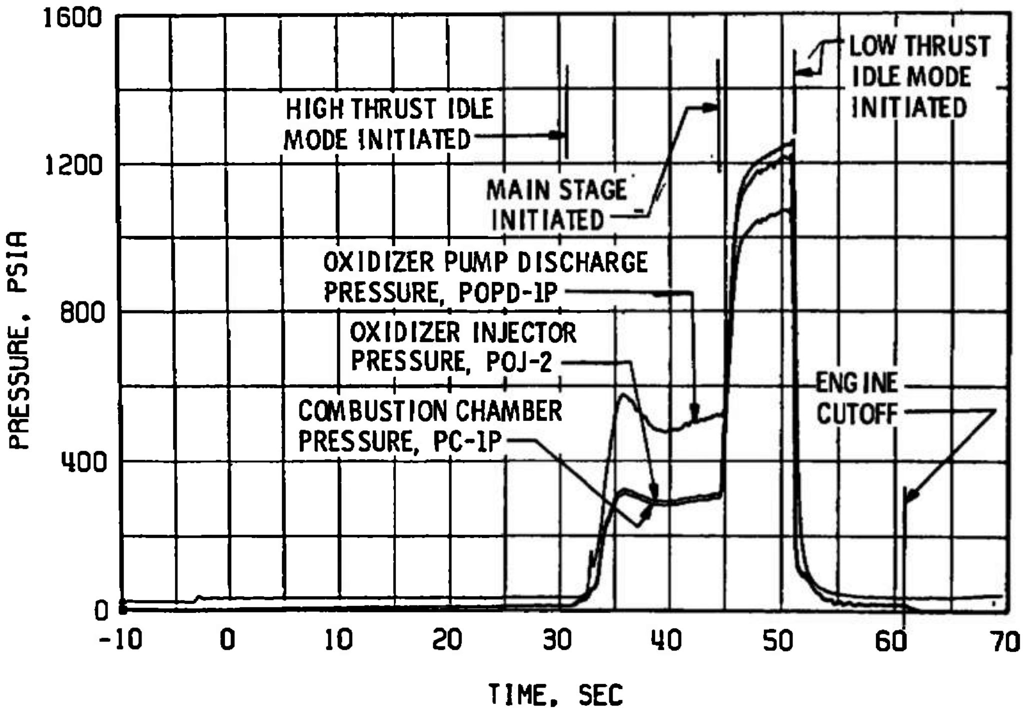


Fig. 30 Engine Total Propellant Flow Rate and Injector Mixture Ratio, Firing 15B



a. Fuel



b. Oxidizer

Fig. 31 Propellant Feed System Performance, Firing 15B

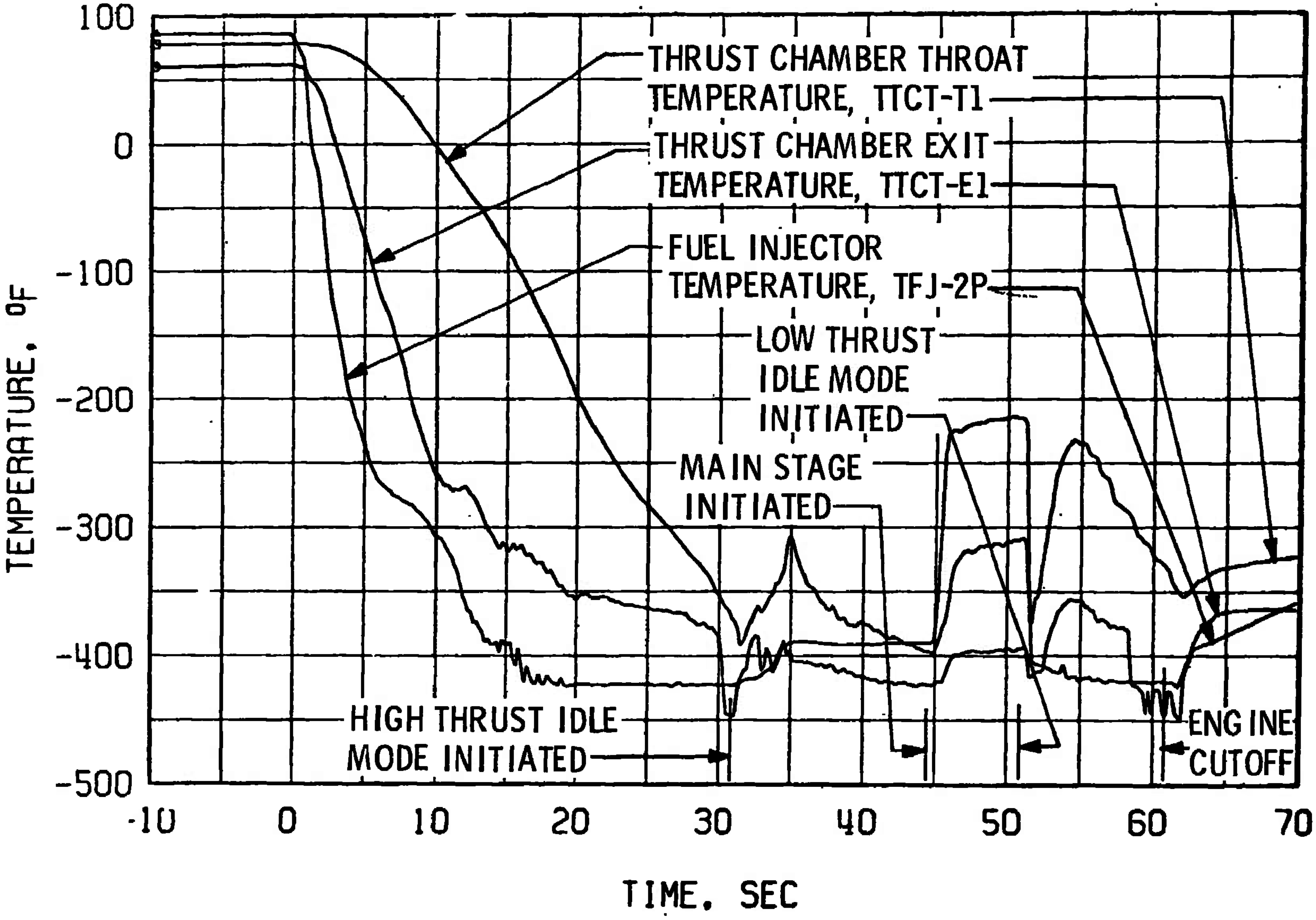


Fig. 32 Thrust Chamber and Injector Chilldown Characteristics, Firing 15B

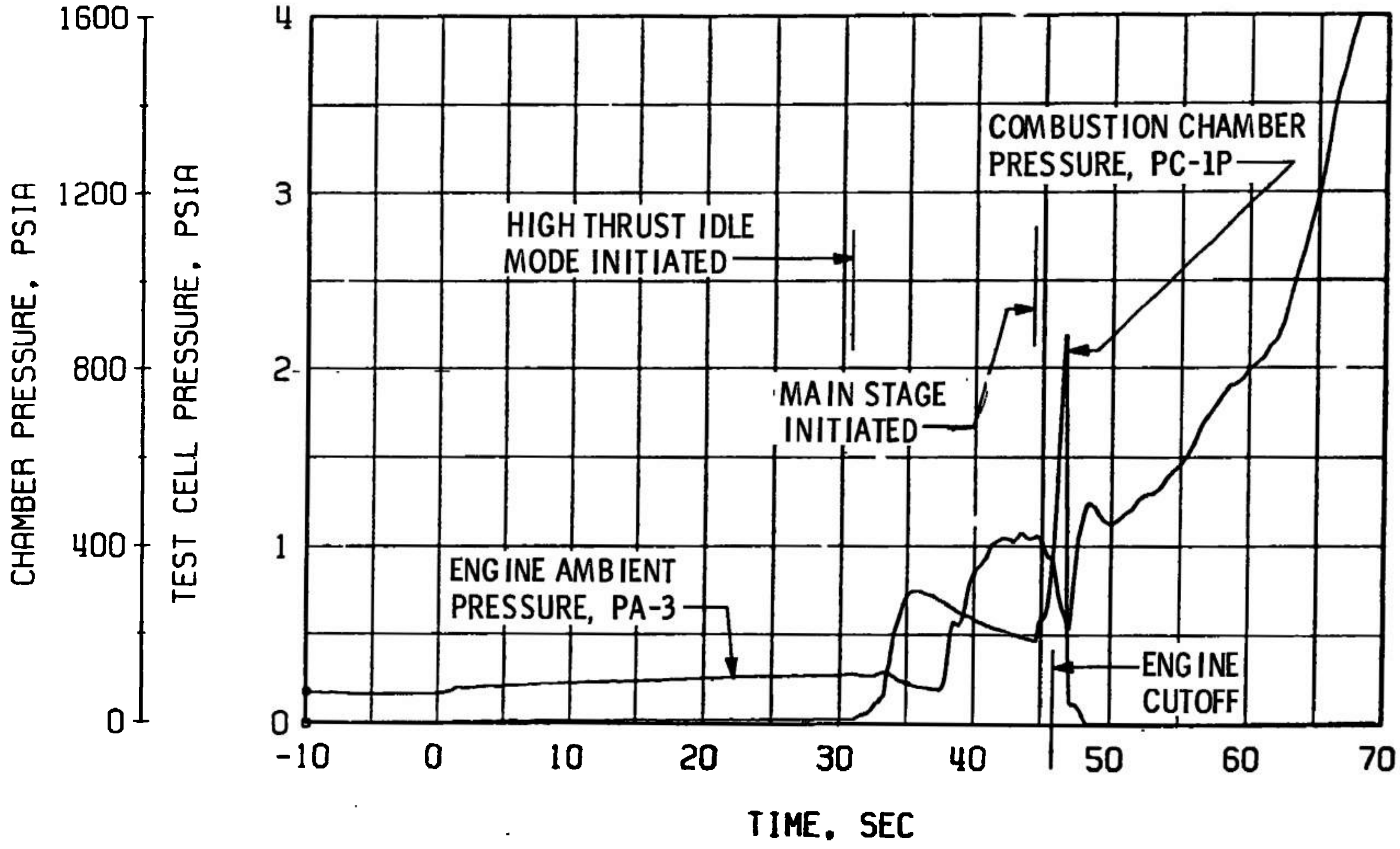


Fig. 33 Engine Ambient and Combustion Chamber Pressures, Firing 15C

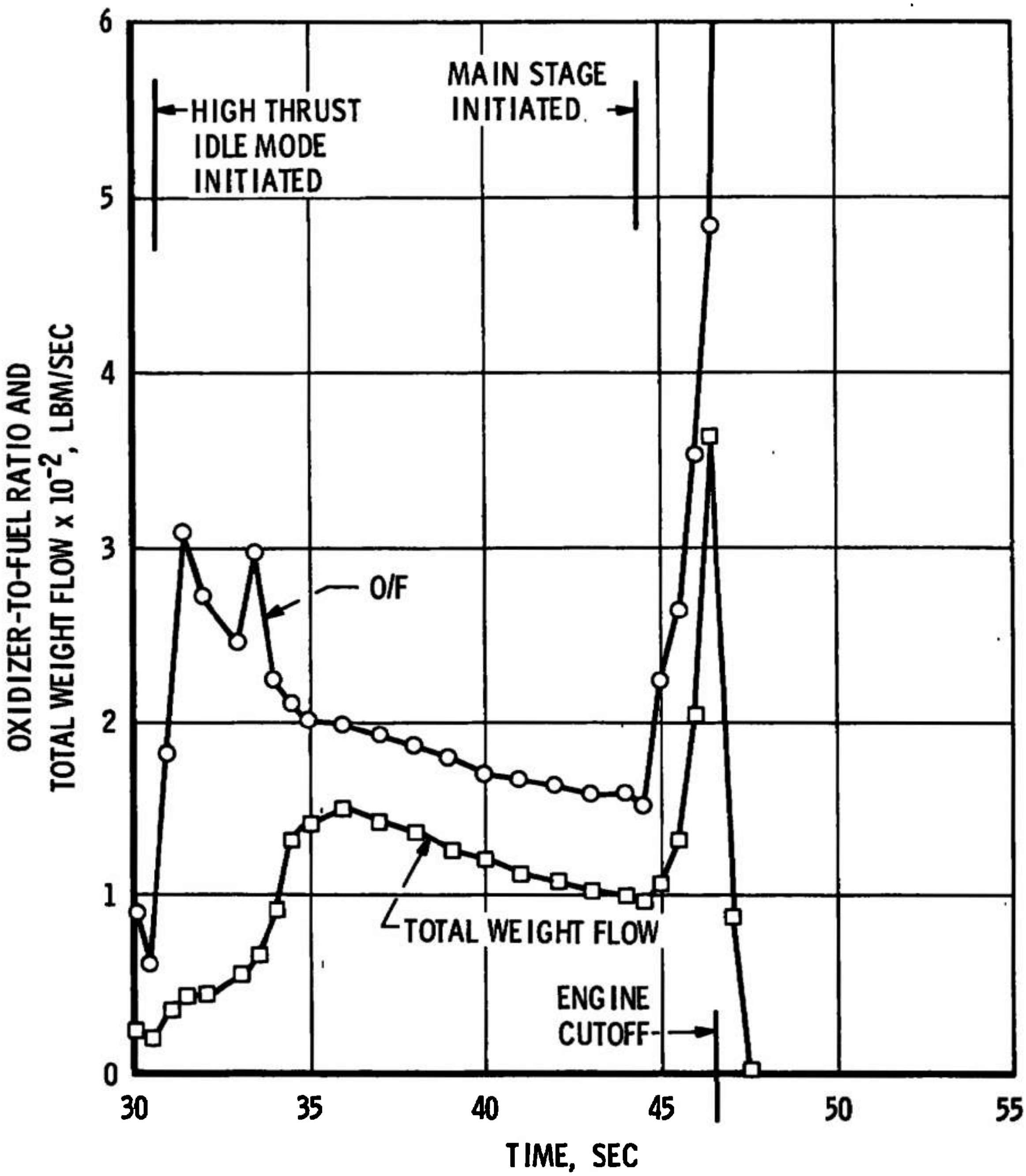
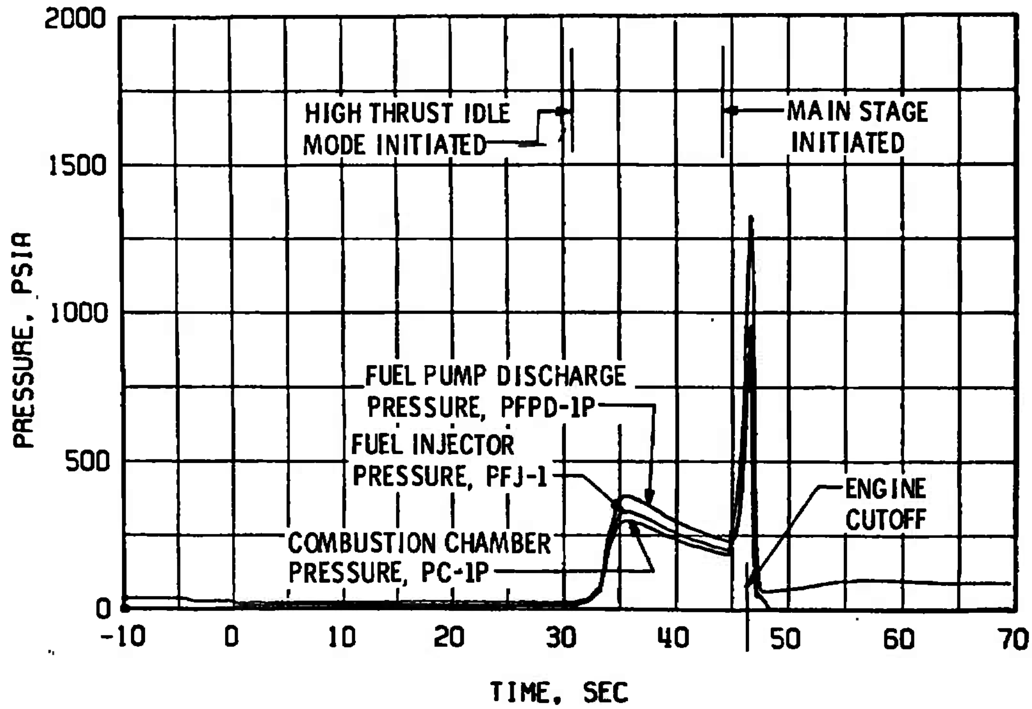
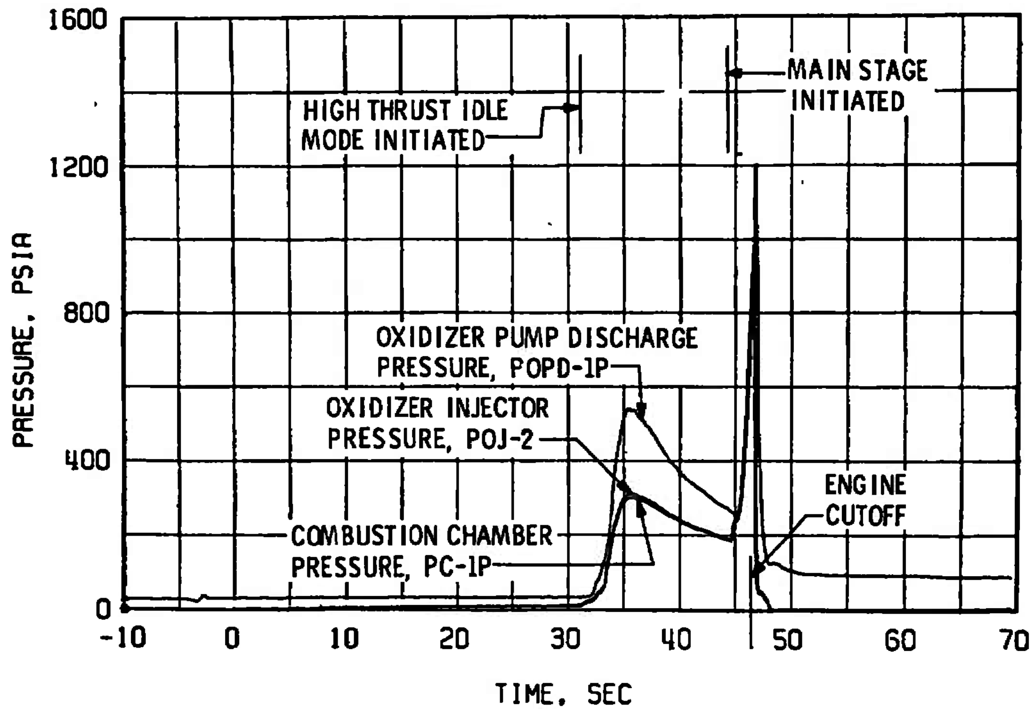


Fig. 34 Engine Total Propellant Flow Rate and Injector Mixture Ratio, Firing 15C



a. Fuel



b. Oxidizer

Fig. 35 Propellant Feed System Performance, Firing 15C

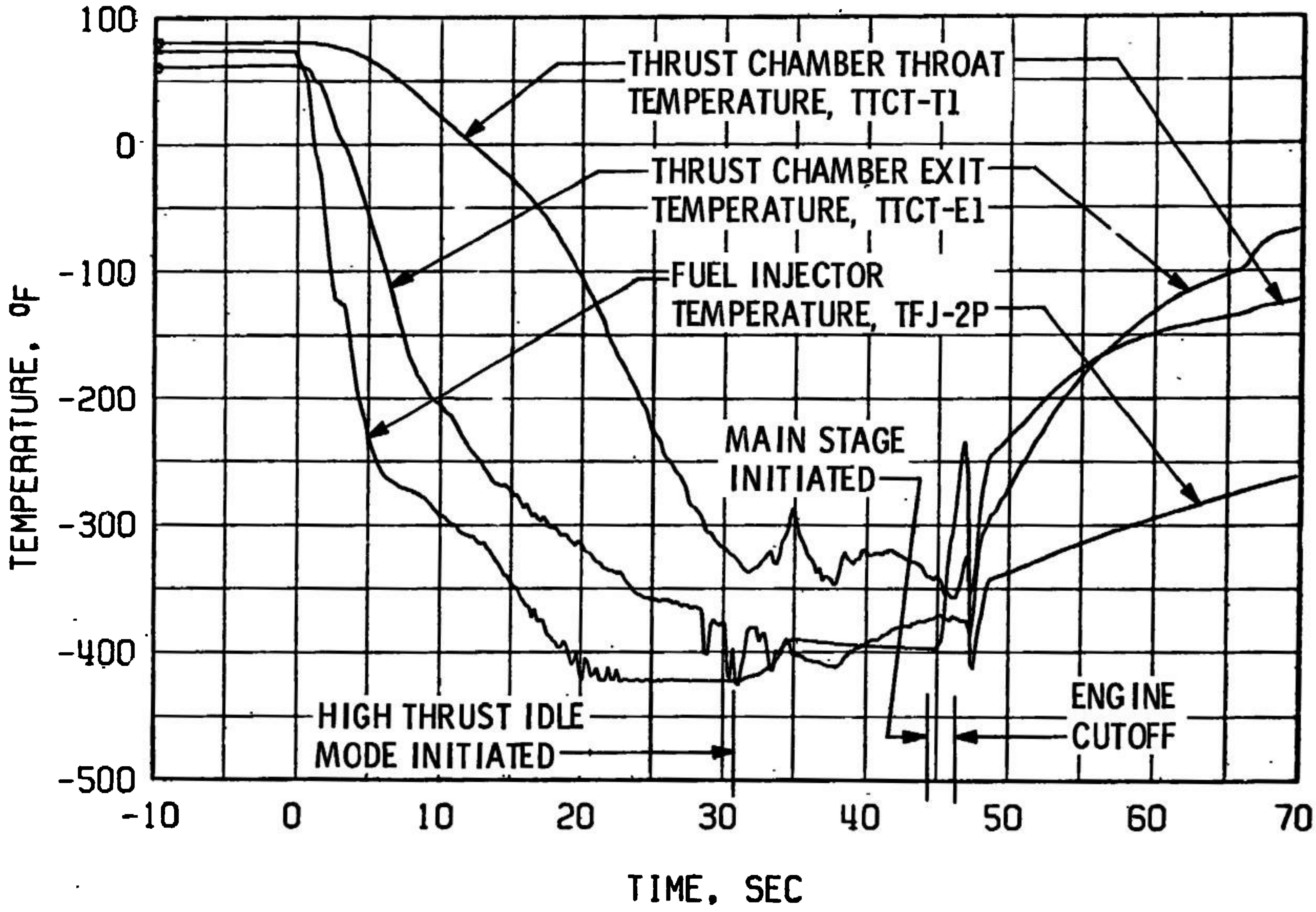


Fig. 36 Thrust Chamber and Injector Chilldown Characteristics, Firing 15C

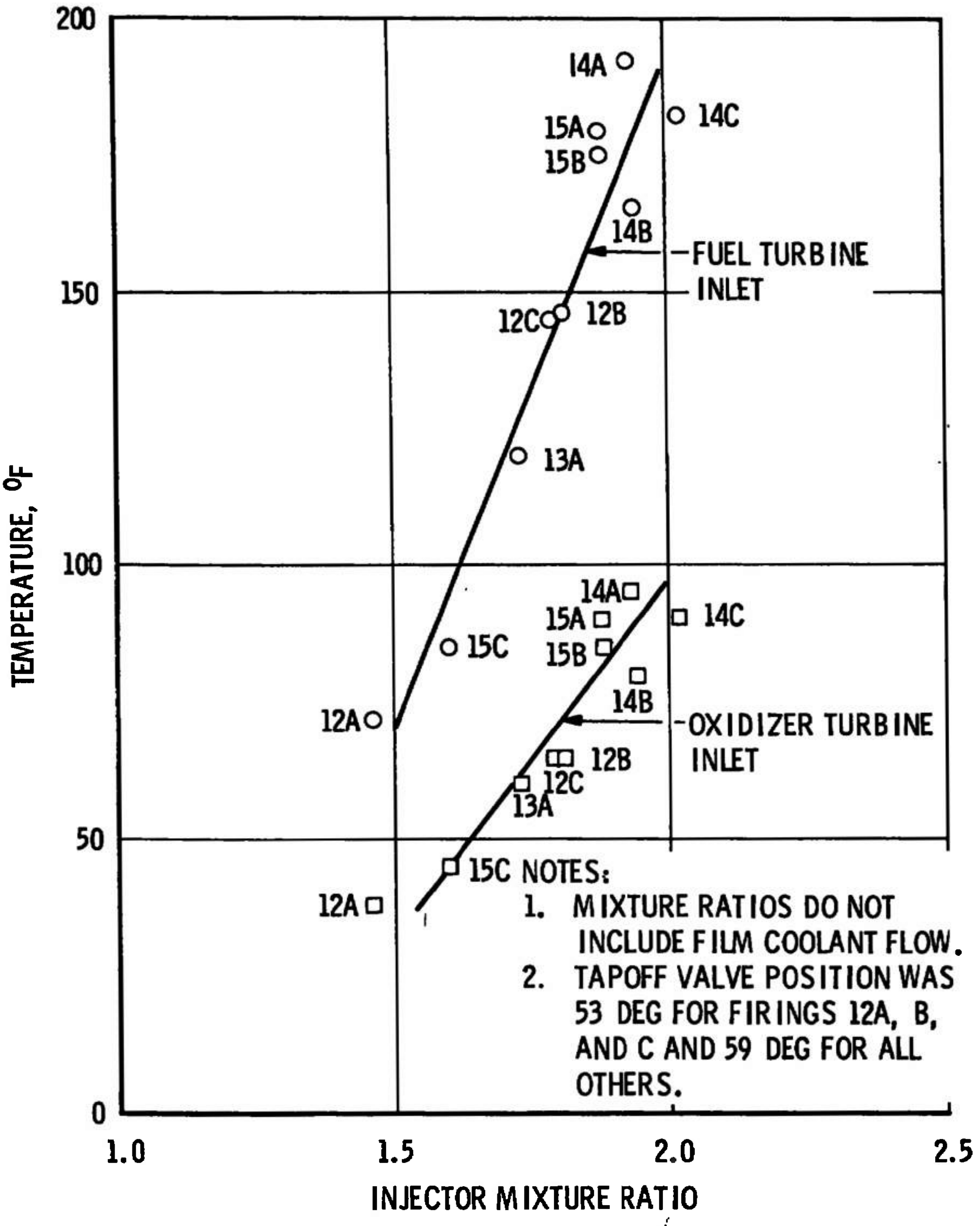
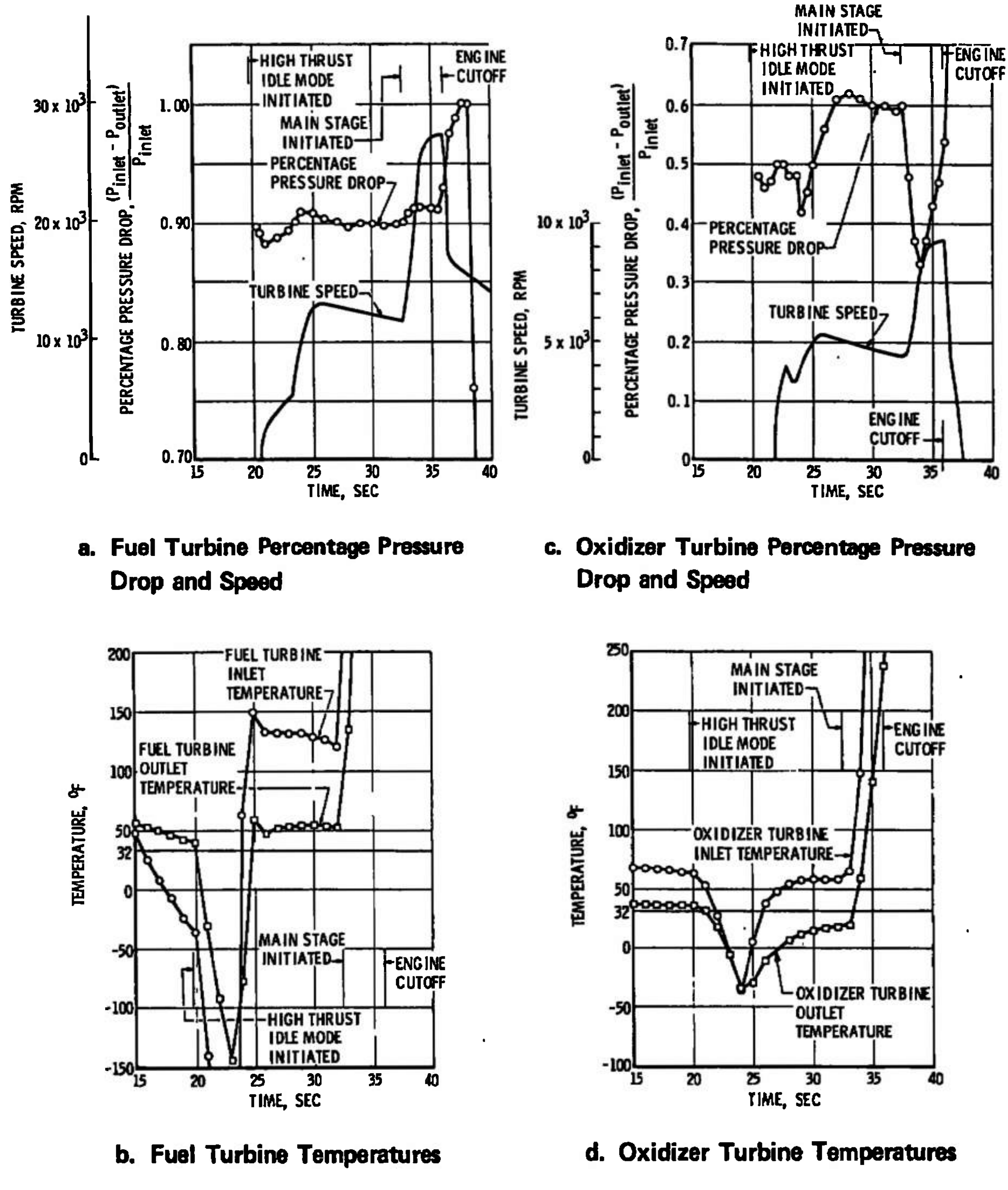


Fig. 37 Mixture Ratio Influence on Turbine Inlet Temperatures



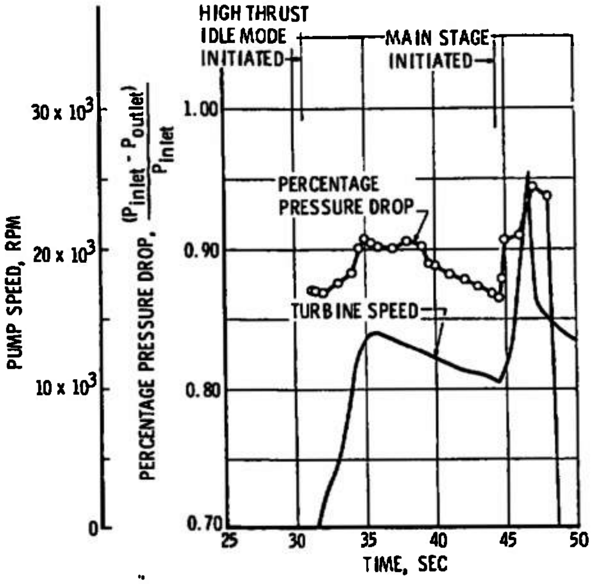
a. Fuel Turbine Percentage Pressure Drop and Speed

c. Oxidizer Turbine Percentage Pressure Drop and Speed

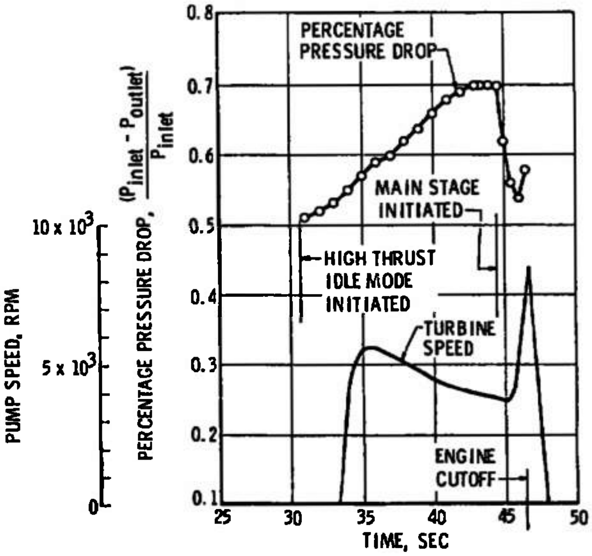
b. Fuel Turbine Temperatures

d. Oxidizer Turbine Temperatures

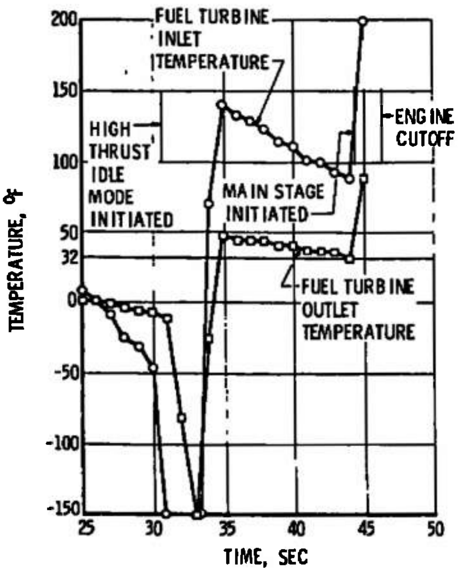
Fig. 38 Turbine Performance, Firing 13A



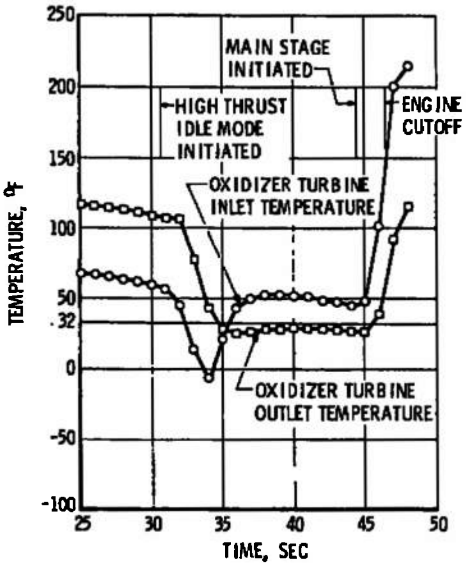
a. **Fuel Turbine Percentage Pressure Drop and Speed**



c. **Oxidizer Turbine Percentage Pressure Drop and Speed**



b. **Fuel Turbine Temperatures**



d. **Oxidizer Turbine Temperatures**

Fig. 39 Turbine Performance, Firing 15C

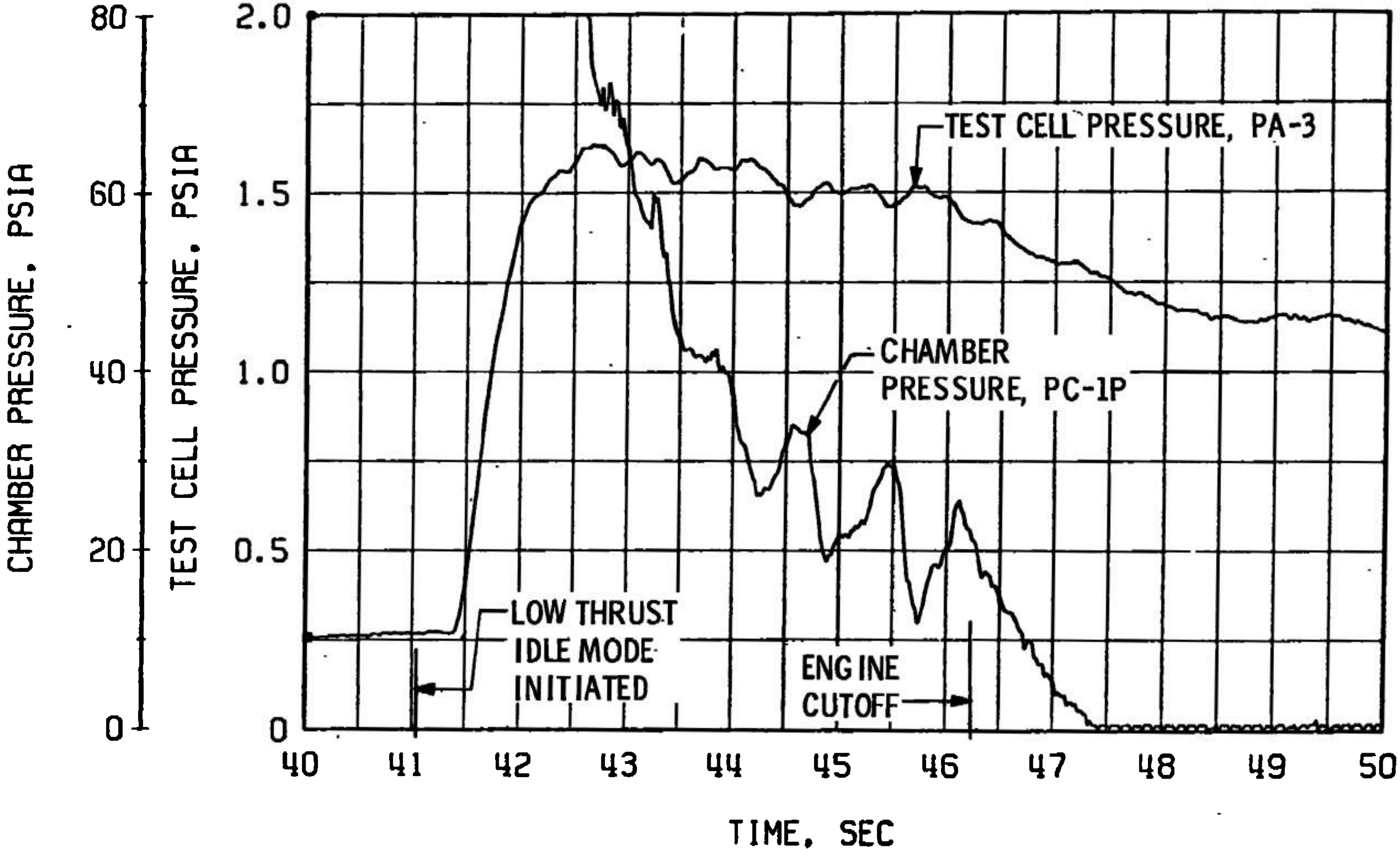
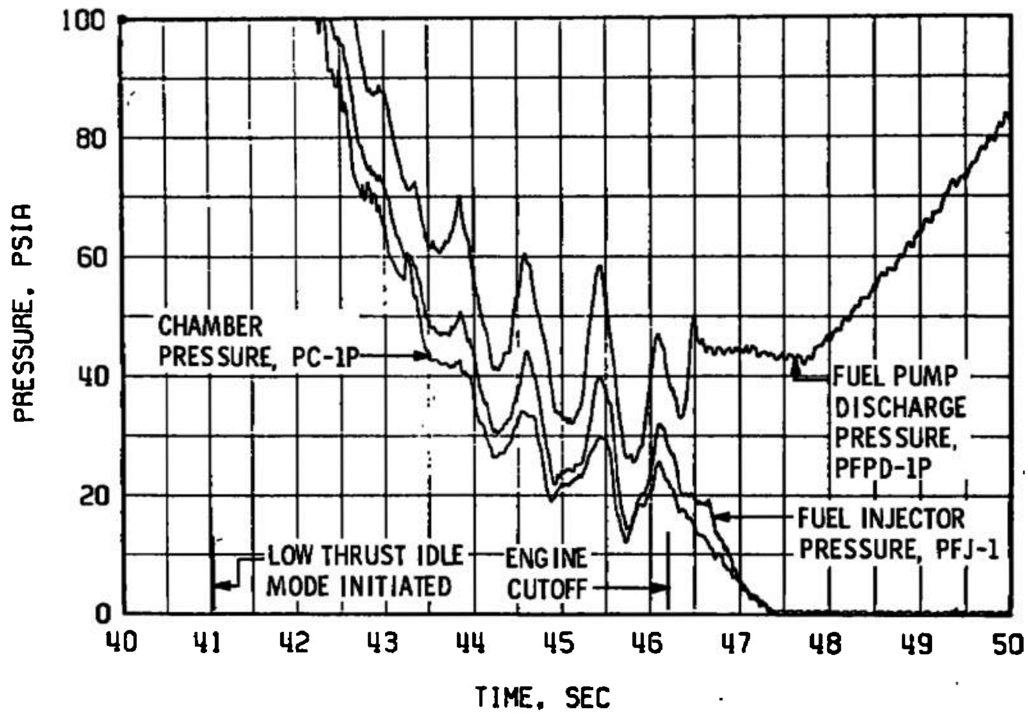
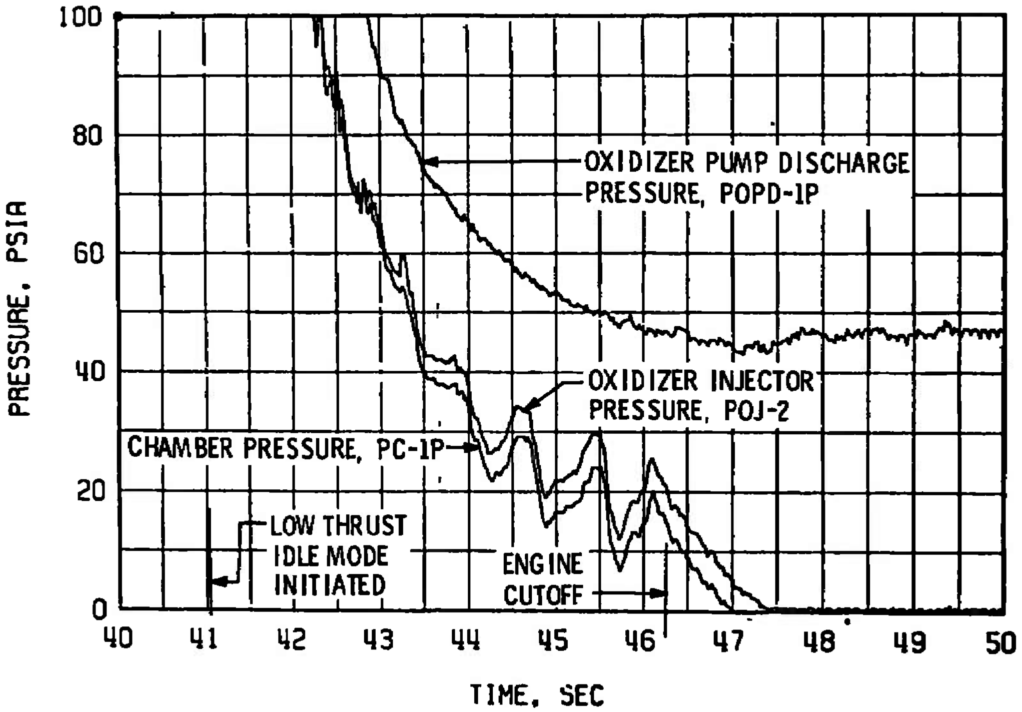


Fig. 40 Post-Main-Stage Low Thrust Idle-Mode Chamber and Engine Ambient Pressures, Firing 14C



a. Fuel



b. Oxidizer

Fig. 41 Post-Main-Stage Low Thrust Idle-Mode Propellant Feed System Performance, Firing 14C

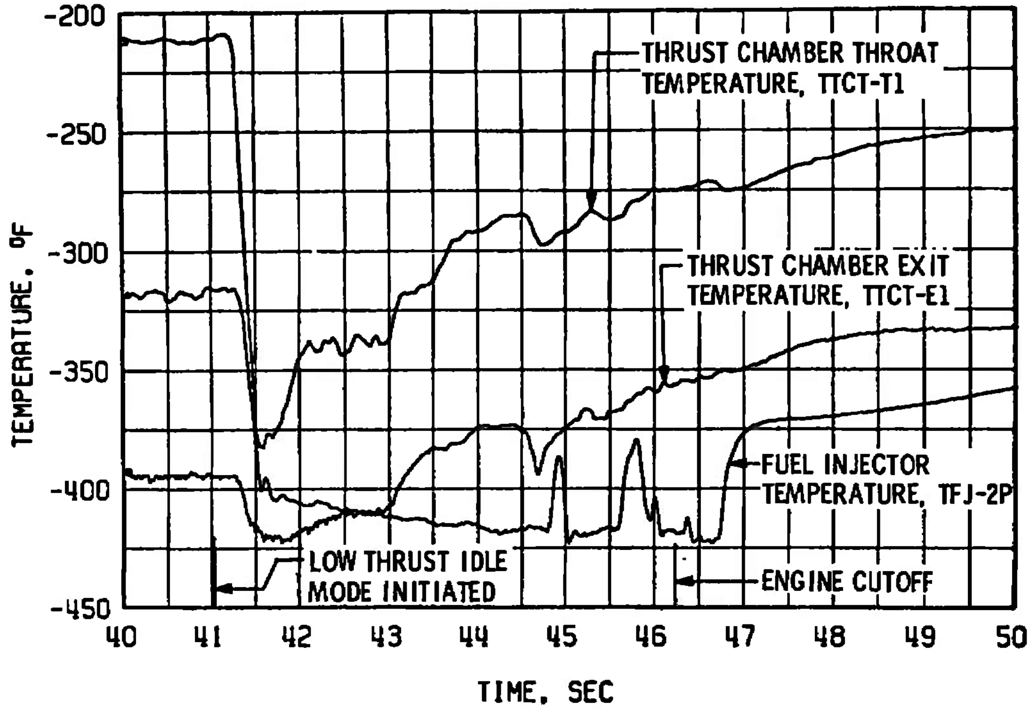


Fig. 42 Post-Main-Stage Low Thrust Idle-Mode Thrust Chamber Temperature Transients, Firing 14C

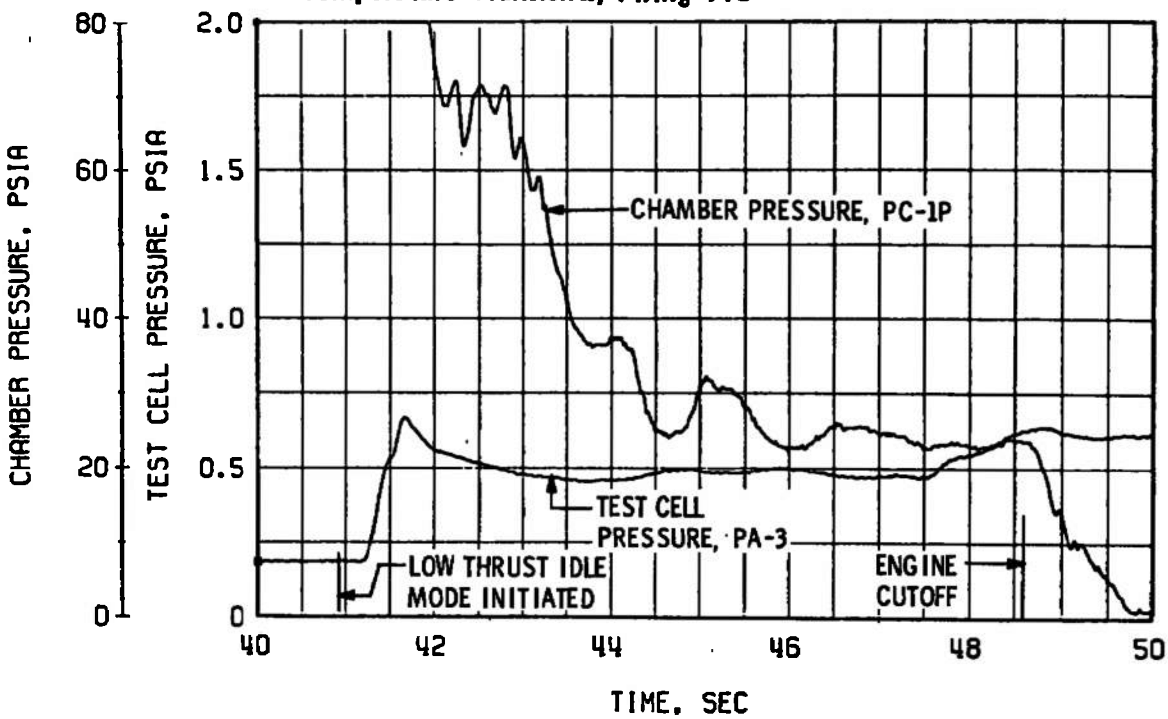
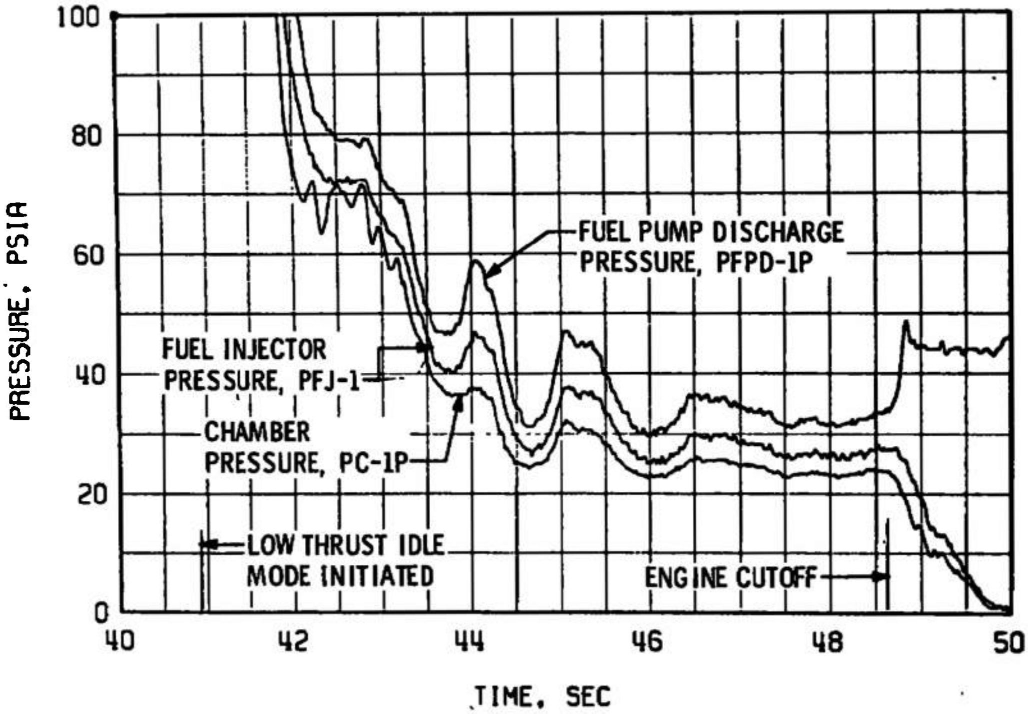
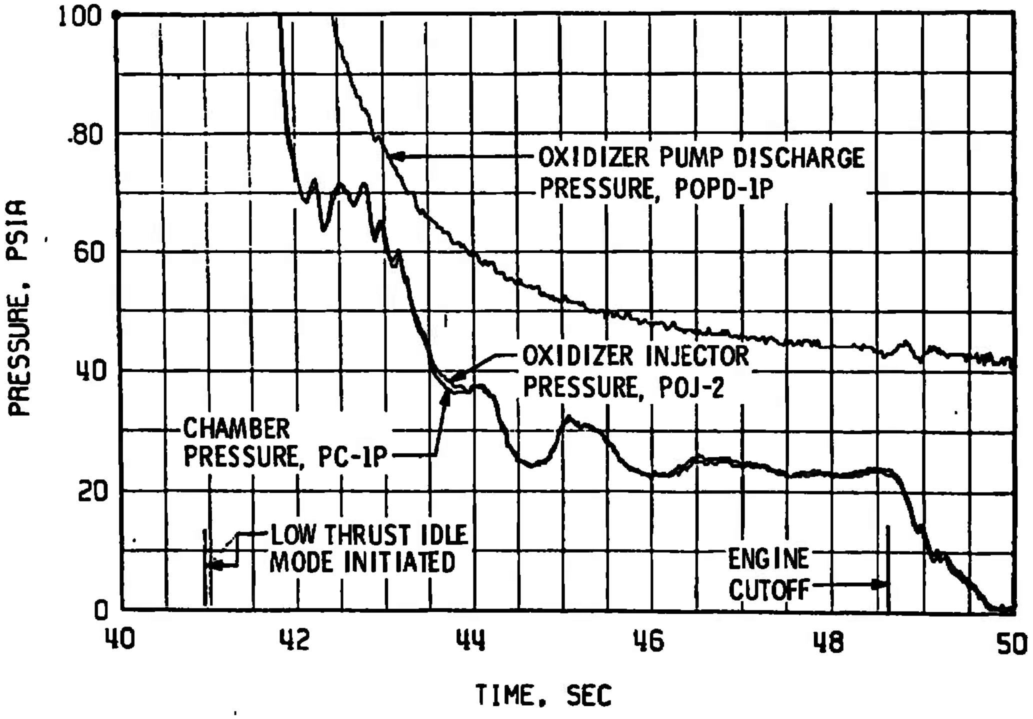


Fig. 43 Post-Main-Stage Low Thrust Idle-Mode Chamber and Engine Ambient Pressures, Firing 15A



a. Fuel



b. Oxidizer

Fig. 44 Post-Main-Stage Low Thrust Idle-Mode Propellant Feed System Performance, Firing 15A

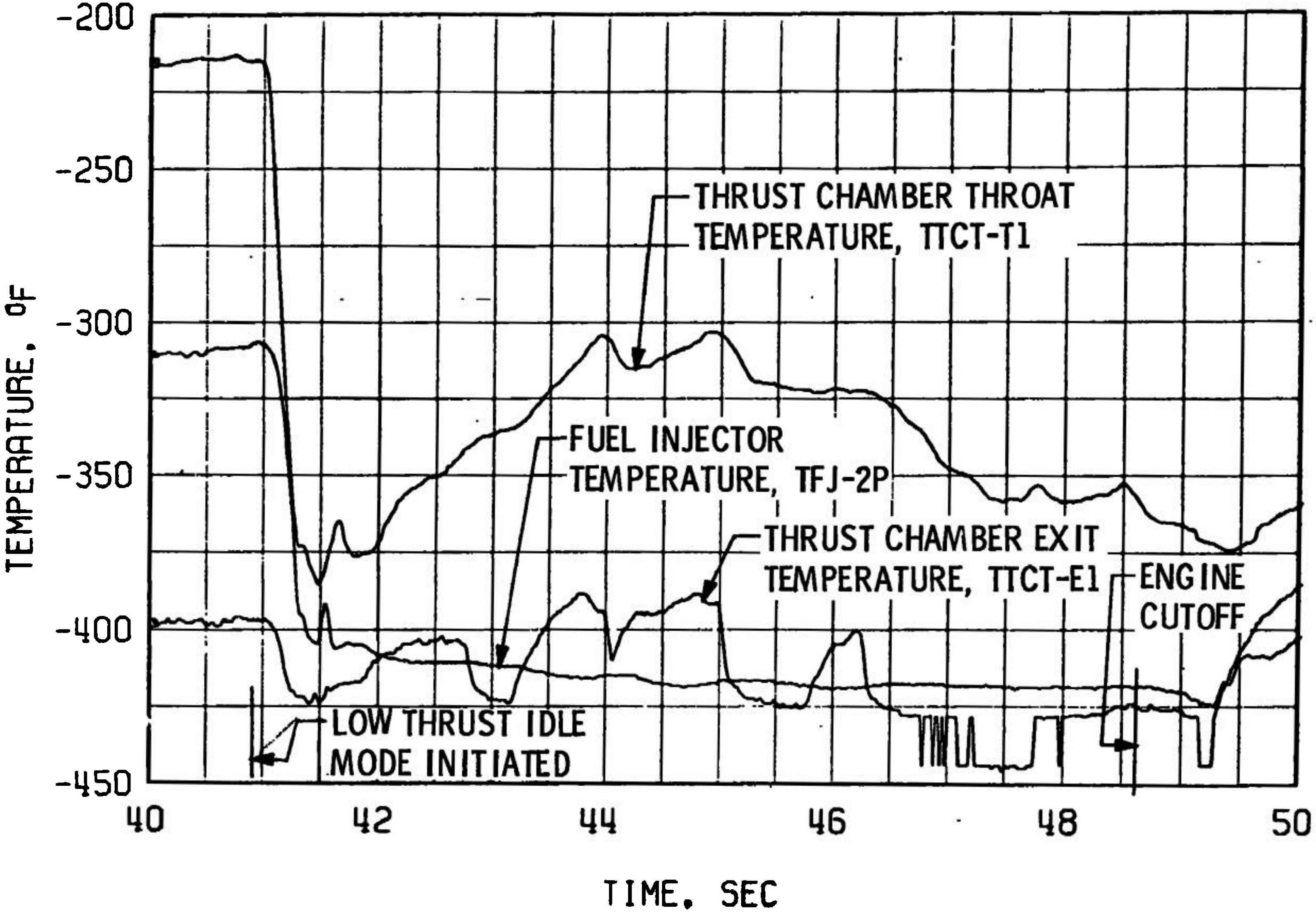


Fig. 45 Post-Main-Stage Low Thrust Idle-Mode Temperature Transients, Firing 15A

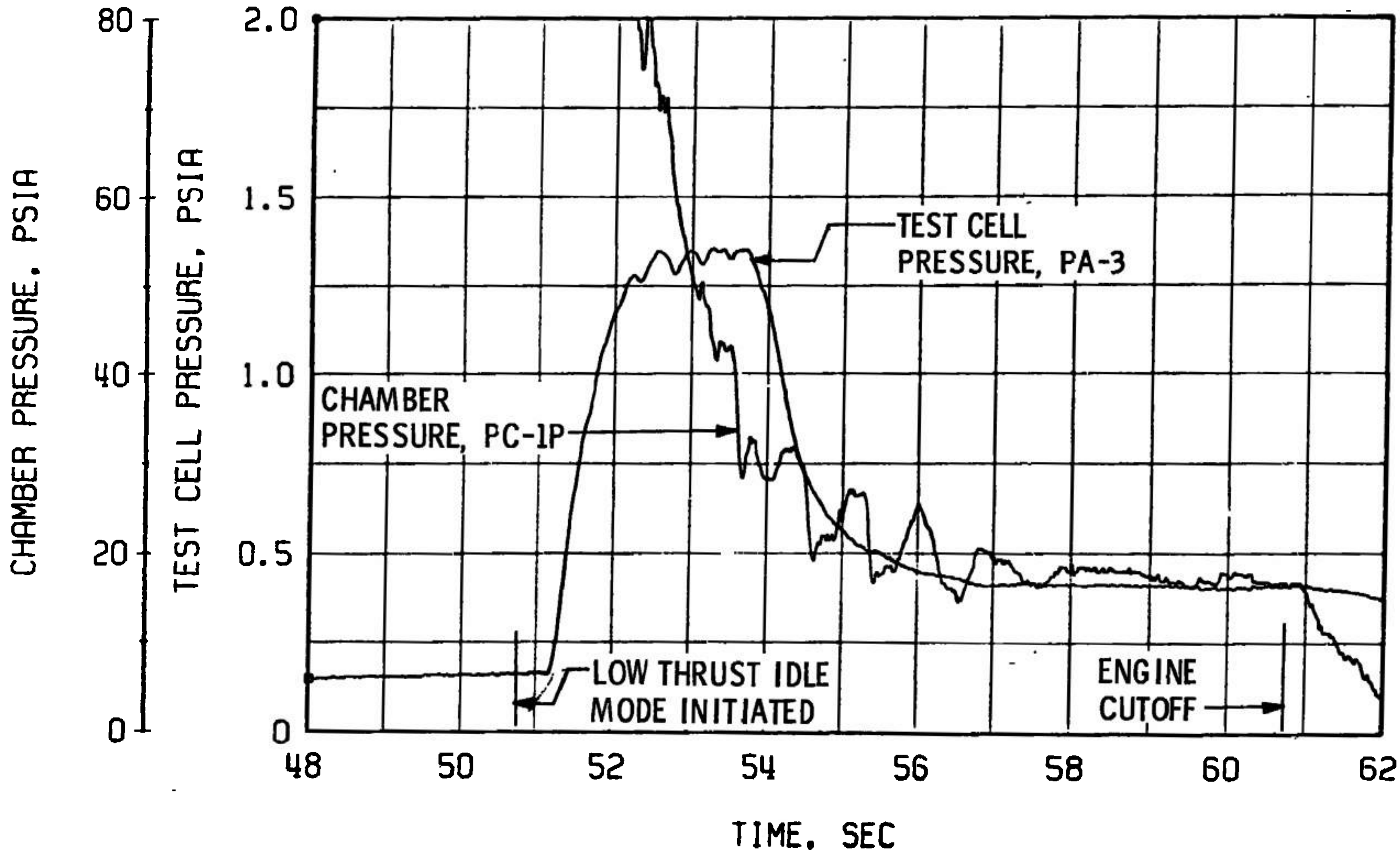
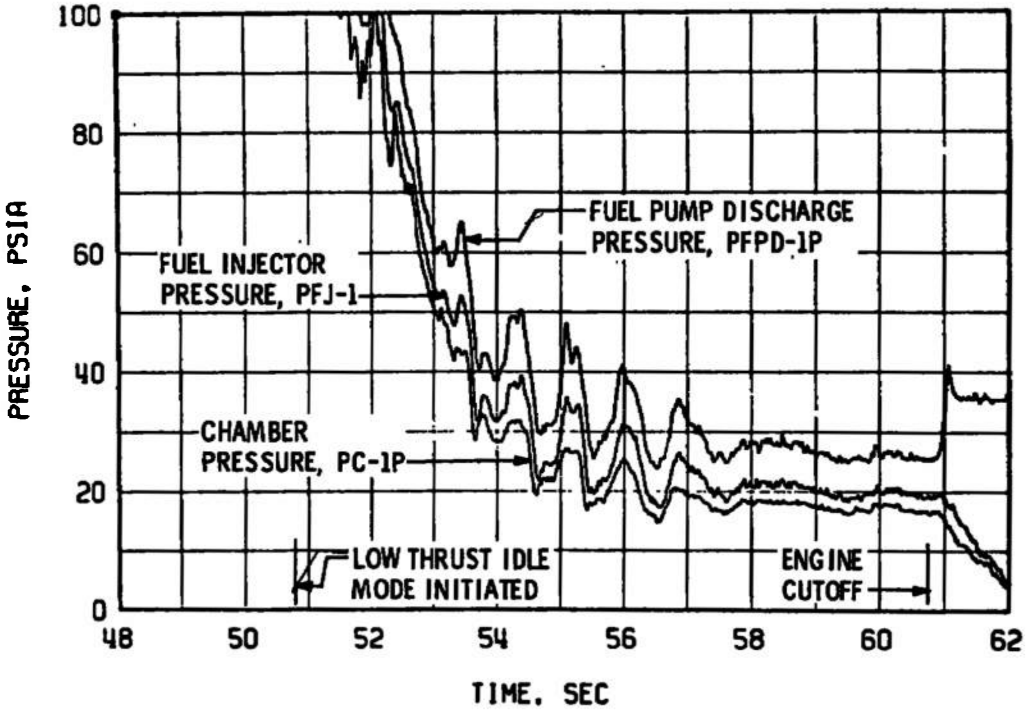
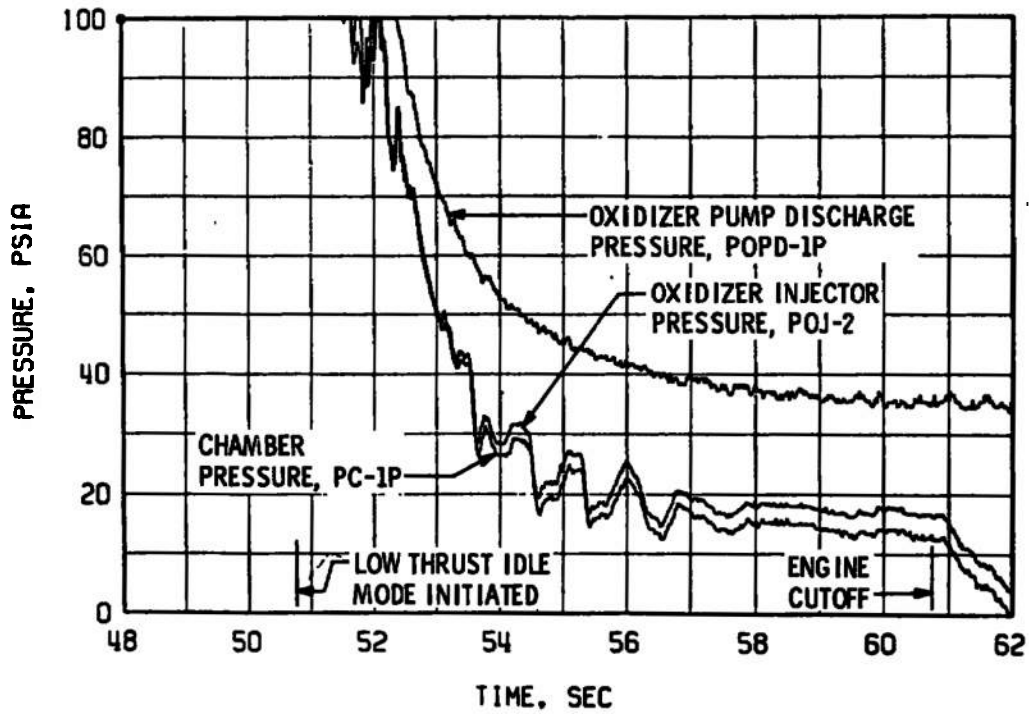


Fig. 46 Post-Main-Stage Low Thrust Idle-Mode Chamber and Engine Ambient Pressures, Firing 15B



a. Fuel



b. Oxidizer

Fig. 47 Post-Main-Stage Low Thrust Idle-Mode Propellant Feed System Performance, Firing 15B

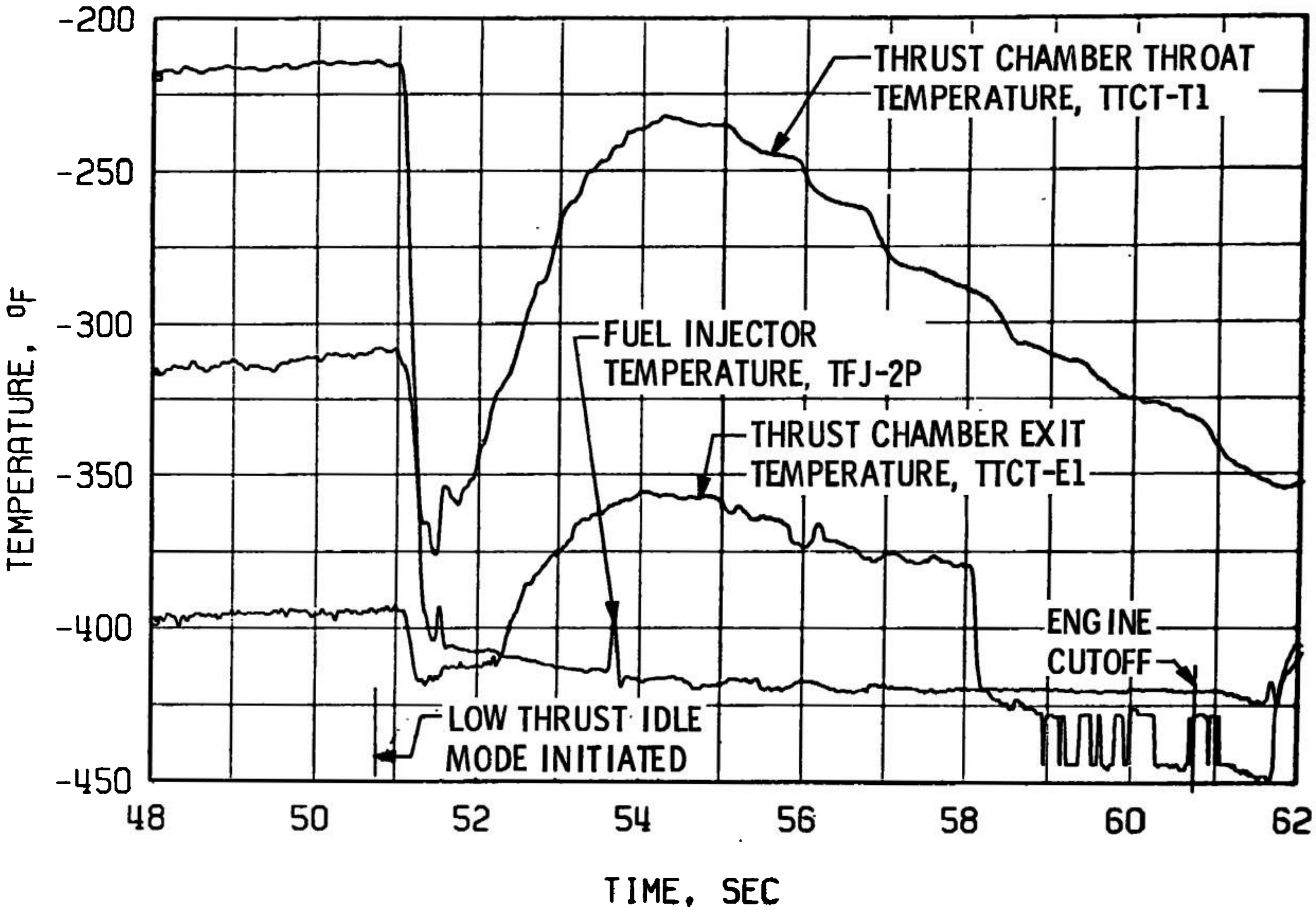
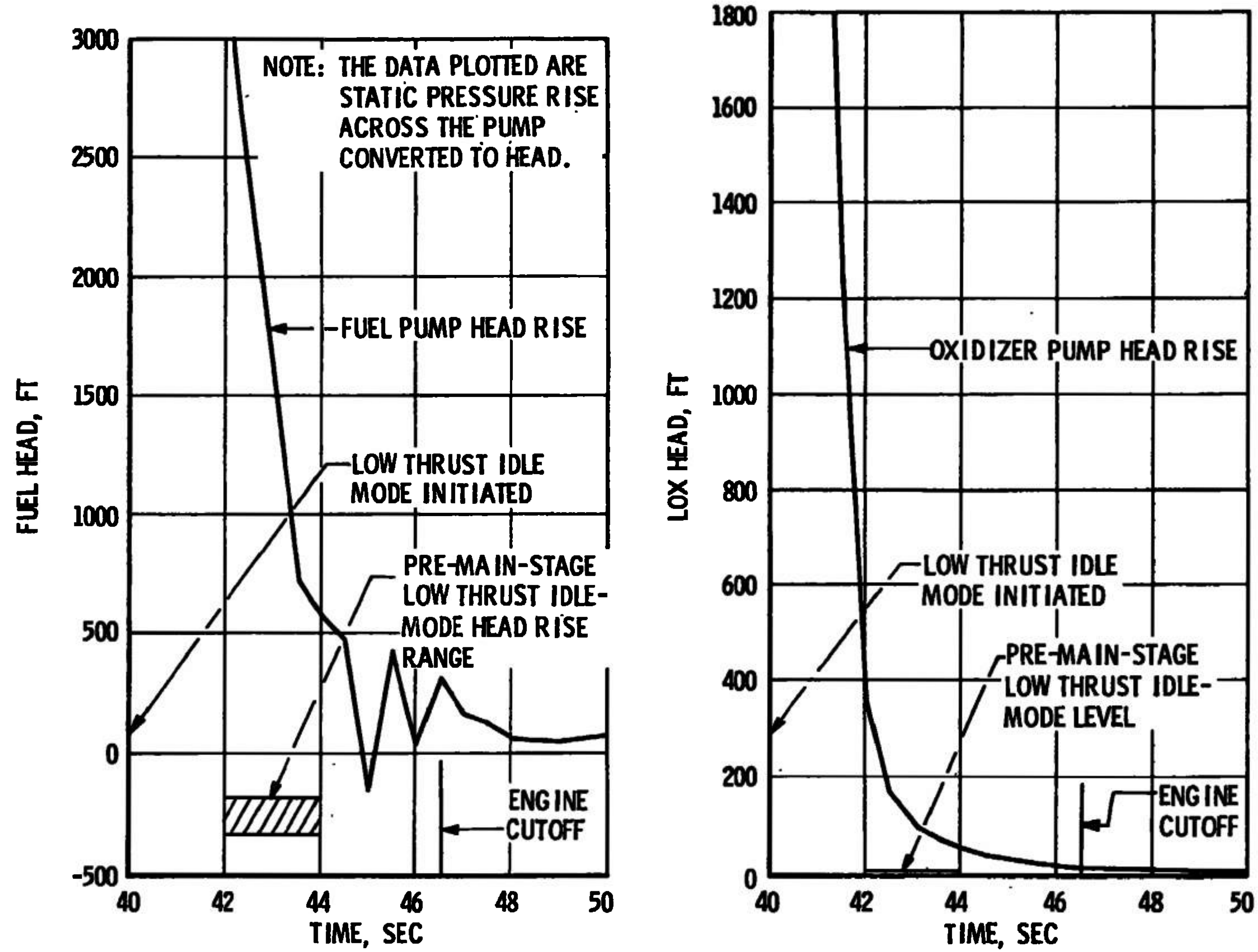
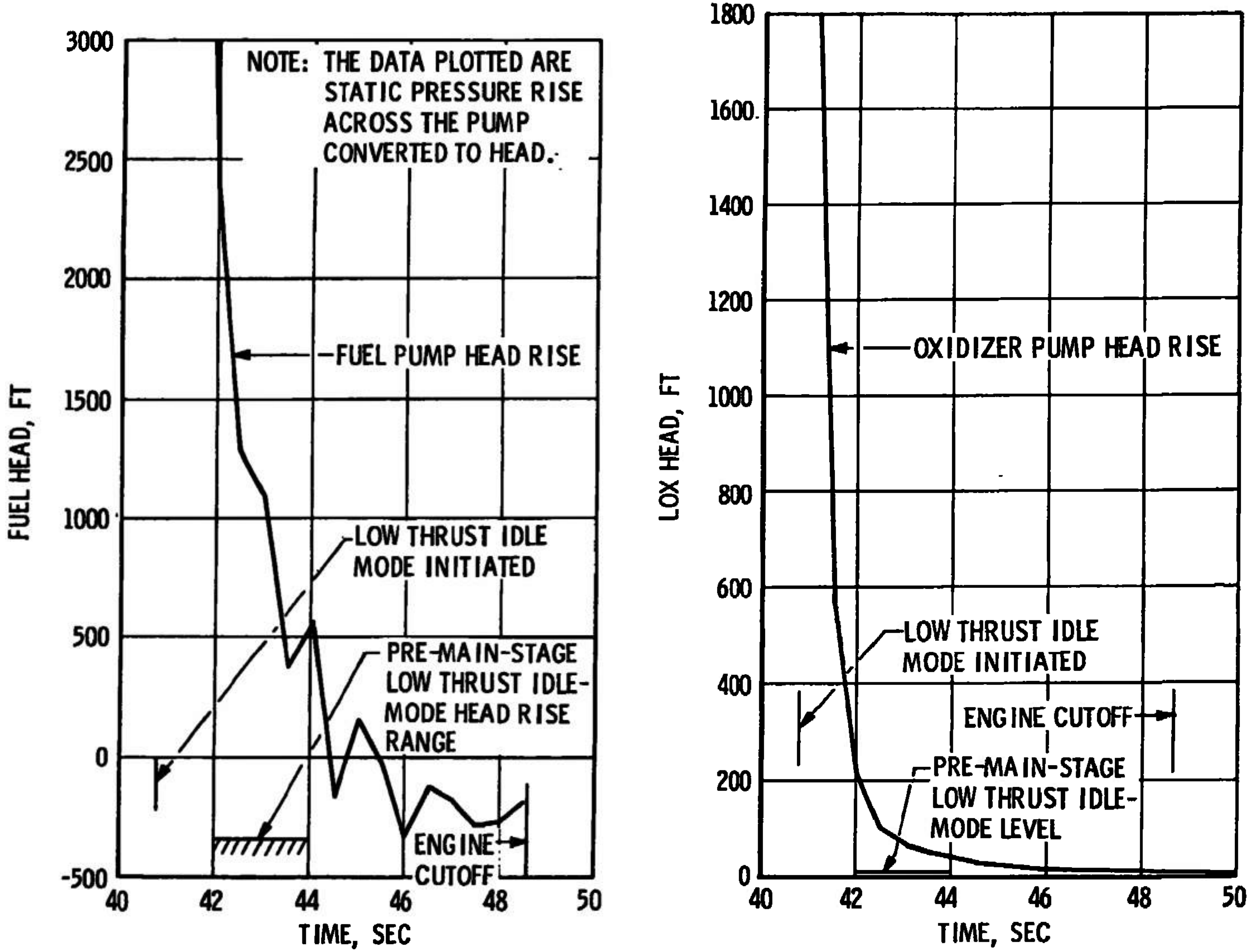


Fig. 48 Post-Main-Stage Low Thrust Idle-Mode Thrust Chamber Temperature Transients, Firing 15B

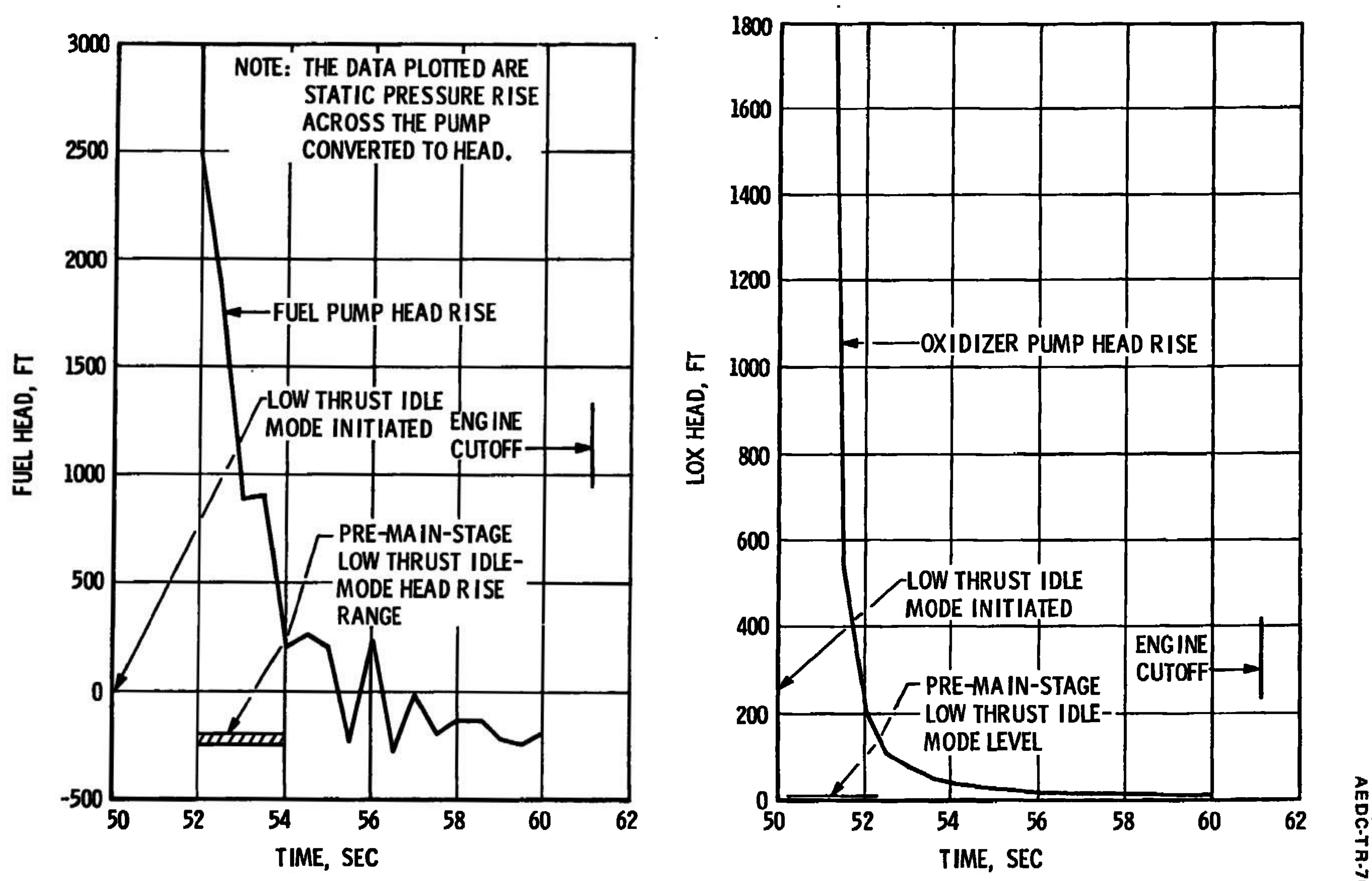


a. Firing 14C

Fig. 49 Pump Head Rise during Post-Main-Stage Low Thrust Idle Mode



b. Firing 15A
Fig. 49 Continued



c. Firing 15B

Fig. 49 Concluded

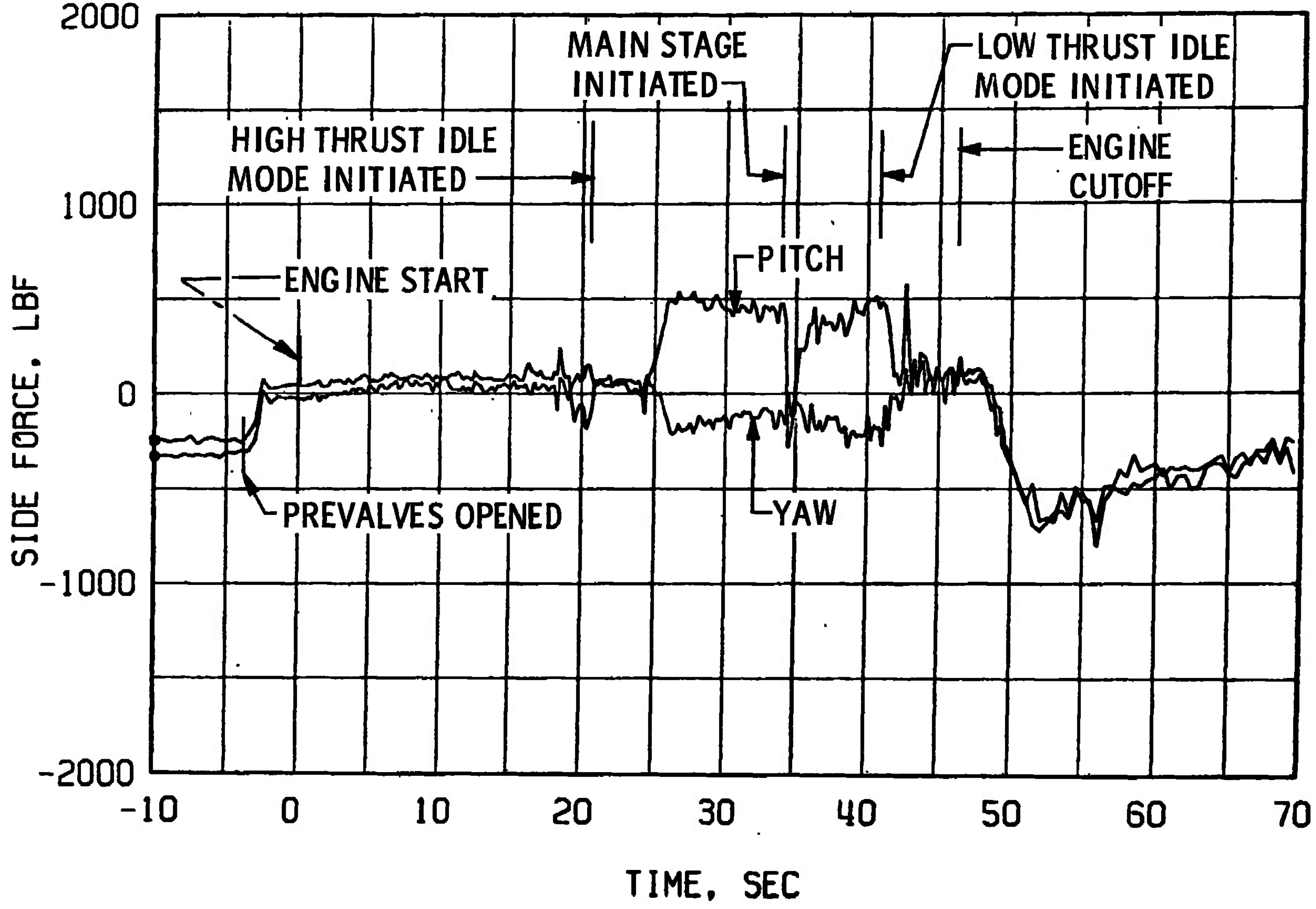


Fig. 50 Representative Post-Main-Stage Low Thrust Idle-Mode Side Forces

TABLE I
MAJOR ENGINE COMPONENTS
(Effective Test J4-1902-13, -14, and -15)

Part Name	P/N	P/N
Thrust Chamber Body Assembly	99-210620	4094439
Thrust Chamber Injector Assembly	99-210610-71	4087381
Augmented Spark Igniter Assembly	EWR113811-21	4901310
Ignition Detector Probe 1	3243-2	016
Ignition Detector Probe 2	3423-1	003X
Fuel Turbopump Assembly	99-461500-31	R004-1A
Oxidizer Turbopump Assembly	99-460430-21	S003-0A
Main Fuel Valve	00-411320X3	8900881
Main Oxidizer Valve	00-411225X4	8900929
Idle-Mode Valve	99-411385	8900867
Thrust Chamber Bypass Valve	99-411180-X1	8900954
Hot Gas Tapoff Valve	99-557824-X2	8900847
Propellant Utilization Valve	99-251455X5	8900911
Electrical Control Package	99-503670-11	4097588
Engine Instrumentation Package	99-704641	4097437
Pneumatic Control Package	99-558330	8900817
Restart Control Assembly	99-503680	4097867
Helium Tank Assembly	NA5-260212-1	0002
Oxidizer Flowmeter	251216	4096874
Fuel Flowmeter	251225	4096875
Fuel Inlet Duct Assembly	409900-11	6631788
Oxidizer Inlet Duct Assembly	409899	4052289
Fuel Pump Discharge Duct	99-411082-7	439
Oxidizer Pump Discharge Duct	99-411082-5	439
Thrust Chamber Bypass Duct	99-411079	439
Fuel Turbine Exhaust Bypass Duct	307879-11	2143580
Hot Gas Tapoff Duct	99-411808-51	7239768
Solid-Propellant Turbine Starters Manifold	99-210921-11	7216433
Heat Exchanger and Oxidizer Turbine Exhaust Duct	307887	2142922
Crossover Duct	307879	2143592

TABLE II
SUMMARY OF ENGINE ORIFICES

Orifice Name	Part	Diameter, in.	Test Effectivity	Comments
Augmented spark igniter fuel supply line			J4-1902-05	Open Line
Augmented spark igniter oxidizer supply line	99-652050	0.0999	J4-1902-05	
Film coolant flow		0.581	J4-1902-08	EWR 121099
Thrust chamber bypass line	99-406384	1.500 2.000	J4-1902-13 J4-1902-14 J4-1902-15	EWR 121504 EWR 121512 EWR 121520 open line
Oxidizer turbine bypass nozzle	99-210924	1.996	J4-1902-05	
Film coolant venturi		1.027 inlet 0.744 throat	J4-1902-05	$C_D = 0.97$
Oxidizer idle-mode line	99-411092	0.900	J4-1902-11	EWR 121684

TABLE III
ENGINE MODIFICATIONS
(Between Test J4-1902-12 and -15)

Modification	Completion Date	Description of Modification
	Test J4-1902-12	
EWR 121505	5/13/69	Installation of 1.326-in. tapoff valve stop
EWR 121504	5/13/69	Installation of 1.500-in. fuel bypass orifice
	Test J4-1902-13	
EWR 121512	5/19/69	Installation of 2.000-in. fuel bypass orifice
	Test J4-1902-14	
EWR 121518	5/16/69	Change main oxidizer valve 11 to 12 deg
EWR 121520	5/26/69	Removal of 2.000-in. fuel bypass orifice
	Test J4-1902-15	

TABLE IV
ENGINE COMPONENT REPLACEMENTS
(Between Test J4-1902-12 and -15)

Replacement	Completion Date	Component Replaced
Test J4-1902-12		
None		
Test J4-1902-13		
None		
Test J4-1902-14		
None		
Test J4-1902-15		

TABLE V
ENGINE PURGE SEQUENCE

Purge	Requirement	SPTS Installed	Air On	Propellant Drop	Engine Start	Cutoff / Coast Period	Propellant Drop	Restart	Cutoff (Last Firing)
Oxidizer dome and idle-mode compartment	Nitrogen, 600 ± 25 psia 100 to 150°F at customer connect panel (150 scfm)								Air Off
Fuel and oxidizer turbine	Nitrogen, 100 to 150°F at customer connect panel								
Thrust chamber jacket, film coolant, and turbopump purges	Helium, 150 ± 25 psia 50 to 150°F at customer connect panel (125 scfm)				(*)	30 min (**) (†)		(*)	30 min
SPTS conditioning	Nitrogen, -50 to 140°F	1, 2, and 3				Remaining SPTS			
Main fuel valve conditioning	Helium, -300°F to ambient			††					

*Engine-supplied liquid-oxygen pump intermediate seal cavity purge
**Anytime facility water is on
†30 min before propellant drop
††Initiate MFV conditioning 30 min before engine start for those firings with temperature requirements

TABLE VI
SUMMARY OF TEST REQUIREMENTS AND RESULTS

Firing Number	J4-1902-13A		J4-1902-14A		J4-1902-14B		J4-1902-14C		J4-1902-15A		J4-1902-15B		J4-1902-15C	
	Target	Actual	Target	Actual	Target	Actual	Target	Actual	Target	Actual	Target	Actual	Target	Actual
Firing Date/Time of Day	5/15/69	13:34	5/22/69	15:41	5/22/69	13:41	5/22/69	16:23	6/4/69	11:08	6/4/69	13:54	6/4/69	13:51
Pressure Altitude at t_0, ft (Ref. 1)	100,000	84,700	100,000	93,800	100,000	67,500	100,000	95,600	100,000	50,600	100,000	58,800	100,000	99,000
Low Thrust Pre-Main Stage Idle-Mode Duration, sec*	20	19.594	20	20.589	20	20.067	20	20.167	20	50.870	30	30.703	30	30.718
High Thrust Idle-Mode Duration, sec*	10	11.507	15	13.518	15	13.773	15	13.782	15	13.745	15	13.720	16	13.722
Main-Stage Duration, sec*	2	3.438	5	6.430	5	7.208	6	7.069	5	6.487	5	5.597	1	2.100
Low Thrust Post-Main Stage Idle-Mode Duration, sec*	---	---	---	---	---	---	6	6.110	7	7.090	10	6.613	---	---
Fuel Pump Inlet Pressure at t_0, psia	40 ± 1	37.4	40 ± 1	39.2	45 ± 1	56.6	31 ± 1	38.6	40 ± 1	35.8	63 ± 1	33.6	27 ± 1	27.1
Fuel Pump Inlet Temperature at t_0, °F	---	-416.6	---	-377.5	---	-316.4	---	-287.7	---	-408.0	---	-312.5	---	-815.5
Fuel Tank Bulk Temperature at t_0, °F	-425 ± 0.4	-423.4	-422 ± 0.4	-422.6	-422 ± 0.4	-423.3	-422 ± 0.4	-422.3	-422 ± 0.4	-422.5	-422 ± 0.4	-422.1	-422 ± 0.4	-422.5
Oxidizer Pump Inlet Pressure at t_0, psia	38 ± 1	38.6	45 ± 1	45.6	35 ± 1	55.1	33 ± 1	66.0	38 ± 1	36.8	33 ± 1	33.2	33 ± 1	31.8
Oxidizer Pump Inlet Temperature at t_0, °F	---	-279.0	---	-286.6	---	-279.5	---	-278.8	---	-287.9	---	-283.0	---	-284.3
Oxidizer Tank Bulk Temperature at t_0, °F	-293 ± 0.4	-290.0	-292 ± 0.4	-296.2	-295 ± 0.4	-293.0	-296 ± 0.4	-295.1	-295 ± 0.4	-295.1	-292 ± 0.4	-296.1	-295 ± 0.4	-294.5
Oxidizer Pump Bearing Temp. before t_0, °F	-100 ± 50	-178	---	-169.5	---	-156.4	---	-175.2	-180 ± 20	-277	-180 ± 20	-189	-180 ± 20	-165
Helium Tank Pressure at t_0, psia	---	3282	5450	3116	Remains from "A"	2869	Remains from "A"	2683	5450	5243	Remains from "A"	-2660	Remains from "A"	3463
Helium Tank Temperature at t_0, °F	---	138	---	129	---	101	---	83	---	124	---	80	---	79
Propellant Utilization Valve Position at t_0	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
Propellant Utilization Valve Excursion, Position/Time	---	---	---	---	---	---	Closed t_0+26	Closed t_0+26.6	---	---	---	---	---	---

*Data reduced from oscillograph

TABLE VII
ENGINE VALVE TIMINGS

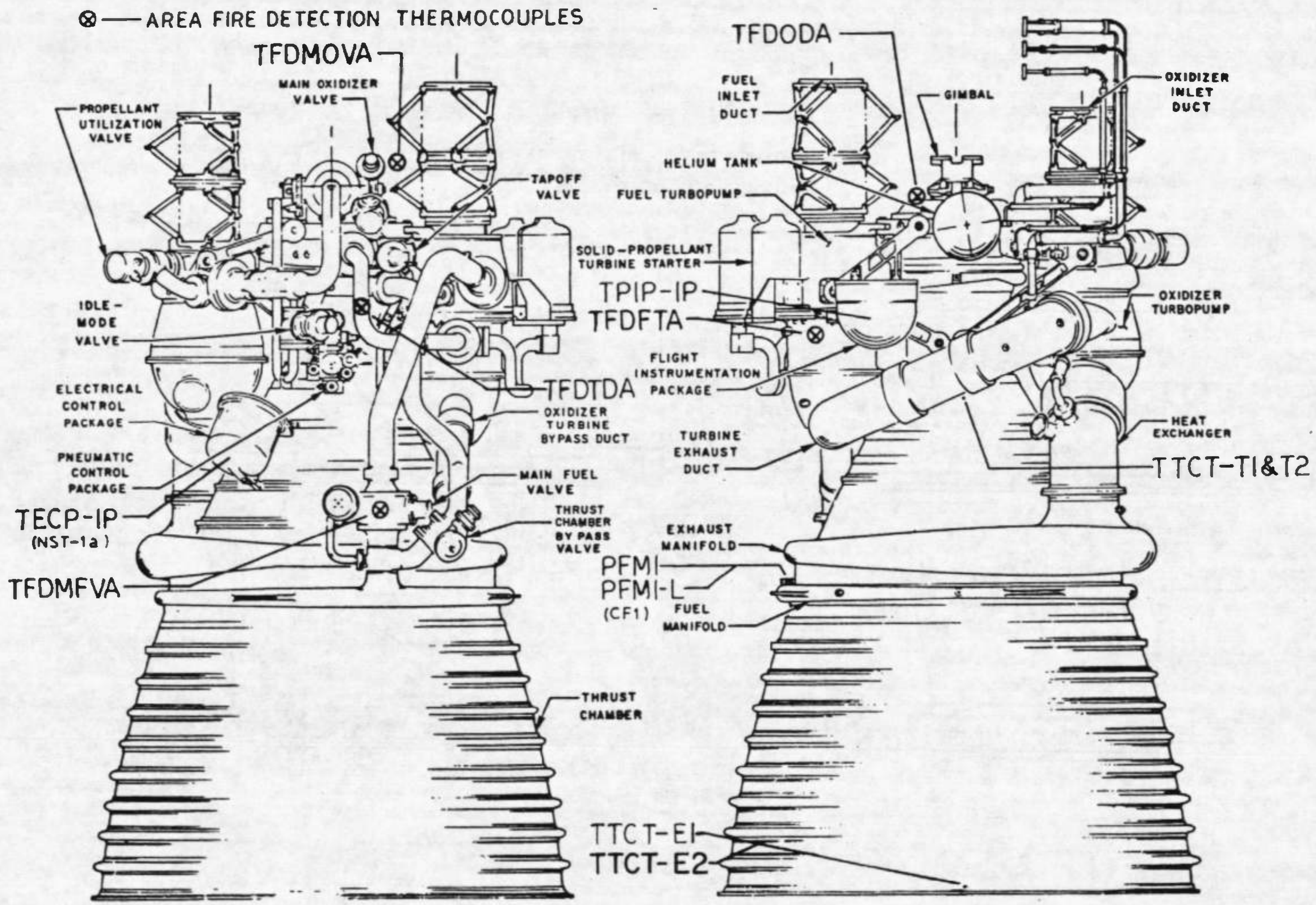
Test J4-1902-	Firing	START: Main Fuel Valve: Time of Opening Signal	Main Fuel Valve: Valve Delay Time, sec	Main Fuel Valve: Valve Opening Time, sec	Idle-Mode Oxidizer Valve: Time of Opening Signal	Idle-Mode Oxidizer Valve: Valve Delay Time, sec	Idle-Mode Oxidizer Valve: Valve Opening Time, sec	Hot Gas Tapoff Valve: Time of Opening Signal	Hot Gas Tapoff Valve: Valve Delay Time, sec	Hot Gas Tapoff Valve: Valve Opening Time, sec	Main Oxidizer Valve First Stage: Time of Opening Signal	Main Oxidizer Valve First Stage: Valve Delay Time, sec	Main Oxidizer Valve First Stage: Valve Opening Time, sec	Main Oxidizer Valve Second Stage: Time of Opening Signal	Main Oxidizer Valve Second Stage: Valve Delay Time, sec	Main Oxidizer Valve Second Stage: Valve Opening Time, sec	Thrust Chamber Bypass Valve: Time of Closing Signal	Thrust Chamber Bypass Valve: Valve Delay Time, sec	Thrust Chamber Bypass Valve: Valve Closing Time, sec
12	Final Sequence	0	0.050	0.061	0	0.117	0.048	5.180	0.156	0.080	5.180	0.082	0.030	19.973	0.144	0.838	19.973	0.190	0.820
	A	0	0.049	0.049	0	0.110	0.041	19.892	0.186	0.081	19.892	0.081	0.087	38.387	0.158	0.840	32.287	0.189	0.983
14	Final Sequence	0	0.044	0.068	0	0.114	0.040	5.047	0.156	0.082	5.047	0.081	0.032	19.898	0.148	0.839	8.047	2.254	0.840
	A	0	0.048	0.080	0	0.108	0.055	20.389	0.187	0.083	20.389	0.083	0.029	24.407	0.149	0.885	20.589	2.292	0.887
	B	0	0.049	0.058	0	Not Recovered		20.067	0.187	0.085	20.087	0.083	0.028	38.840	0.180	0.850	20.087	2.303	0.840
	C	0	0.049	0.026	0	0.118	0.044	20.189	0.160	0.088	20.188	0.081	0.029	33.931	0.207	0.820	20.189	2.300	0.810
15	Final Sequence	0	0.042	0.083	0	0.112	0.045	4.209	0.137	0.082	4.209	0.084	0.040	17.907	0.154	0.380	17.807	0.209	0.832
	A	0	0.048	0.054	0	0.110	0.048	20.568	0.164	0.088	20.568	0.086	0.036	34.316	0.174	0.840	34.316	0.201	0.703
	B	0	0.048	0.054	0	0.114	0.045	30.701	0.162	0.080	30.701	0.083	0.031	44.421	0.188	0.848	44.421	0.184	1.108
	C	0	0.048	0.038	0	0.118	0.048	30.717	0.185	0.080	30.717	0.085	0.030	44.440	0.189	0.842	44.440	0.207	0.880

Test J4-1902-	Firing	SHUTDOWN: Main Oxidizer Valve: Time of Closing Signal	Main Oxidizer Valve: Valve Delay Time, sec	Main Oxidizer Valve: Valve Closing Time, sec	Hot Gas Tapoff Valve: Time of Closing Signal	Hot Gas Tapoff Valve: Valve Delay Time, sec	Hot Gas Tapoff Valve: Valve Closing Time, sec	Main Fuel Valve: Time of Closing Signal	Main Fuel Valve: Valve Delay Time, sec	Main Fuel Valve: Valve Closing Time, sec	Idle-Mode Oxidizer Valve: Time of Closing Signal	Idle-Mode Oxidizer Valve: Valve Delay Time, sec	Idle-Mode Oxidizer Valve: Valve Closing Time, sec	Thrust Chamber Bypass Valve: Time of Opening Signal	Thrust Chamber Bypass Valve: Valve Delay Time, sec	Thrust Chamber Bypass Valve: Valve Opening Time, sec
12	Final Sequence	22.818	0.076	0.142	22.818	0.063	0.244	30.732	0.073	0.282	30.732	0.060	0.110	22.819	0.270	0.815
	A	35.815	0.088	0.133	33.813	0.089	0.227	32.815	0.080	0.285	35.813	0.079	0.154	32.813	0.308	0.183
14	Final Sequence	28.428	0.083	0.140	25.428	0.073	0.230	22.428	0.078	0.848	25.428	0.087	0.118	25.428	0.188	0.207
	A	40.837	0.083	0.159	40.827	0.089	0.243	40.857	0.079	0.270	40.837	0.074	0.150	40.837	0.880	0.150
	B	41.042	0.083	0.183	41.042	0.065	0.255	41.045	0.083	0.870	41.043	Not Recovered		41.043	0.263	0.150
	C	41.040	0.087	0.122	41.040	0.059	0.270	48.181	0.066	0.250	48.151	0.082	0.138	41.040	0.298	0.170
13	Final Sequence	24.477	0.082	0.142	24.477	0.064	0.250	29.864	0.088	0.238	29.864	0.062	0.108	24.477	0.274	0.813
	A	40.802	0.080	0.155	40.802	0.062	0.888	48.492	0.068	0.854	48.492	0.087	0.151	40.802	0.338	0.184
	B	50.807	0.082	0.148	50.807	0.080	0.288	50.720	0.067	0.253	50.720	0.083	0.140	50.807	0.558	0.186
	C	48.541	0.075	0.188	48.541	0.068	0.238	48.541	0.082	0.288	48.541	0.074	0.142	48.541	0.286	0.188

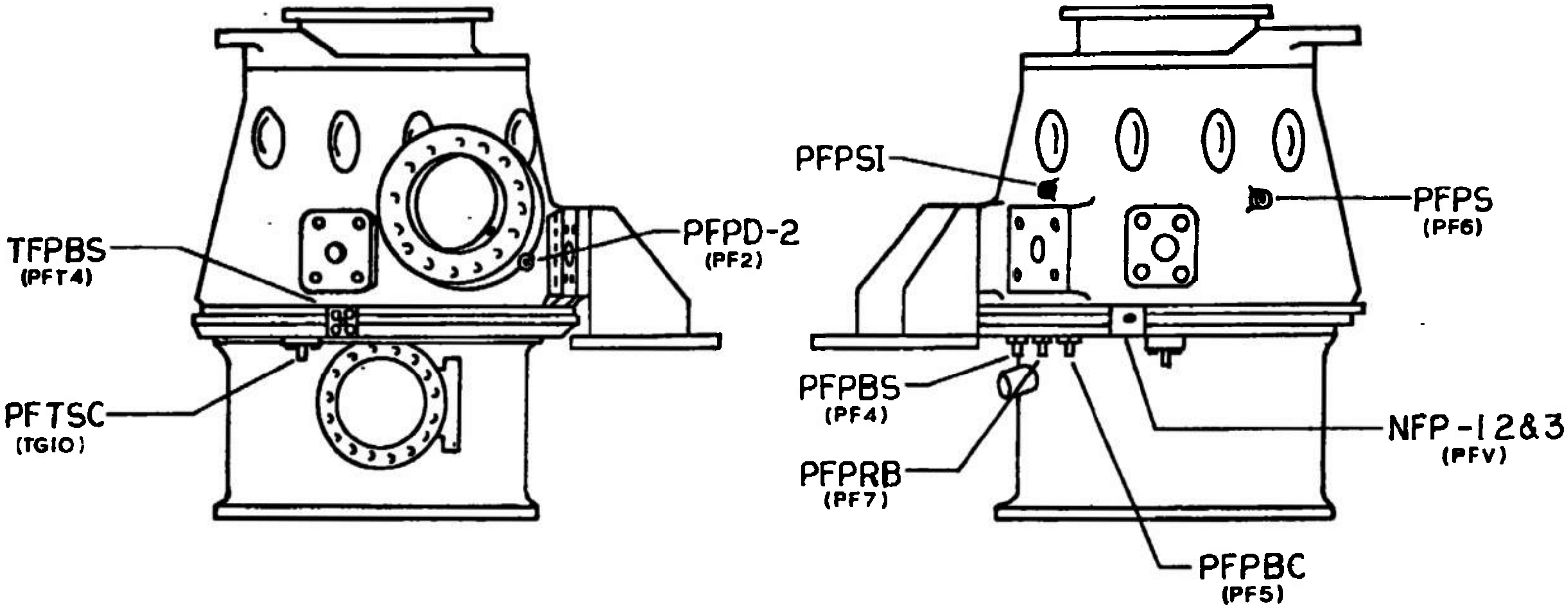
Notes:
1. All valve signal times are referenced to t_0.
2. Valve delay time is the time required for initial valve movement after the valve open or closed solenoid has been energized.
3. Final sequence check is conducted without propellants and within 12 hr before testing.
4. Data are reduced from oscillogram.

APPENDIX III
INSTRUMENTATION

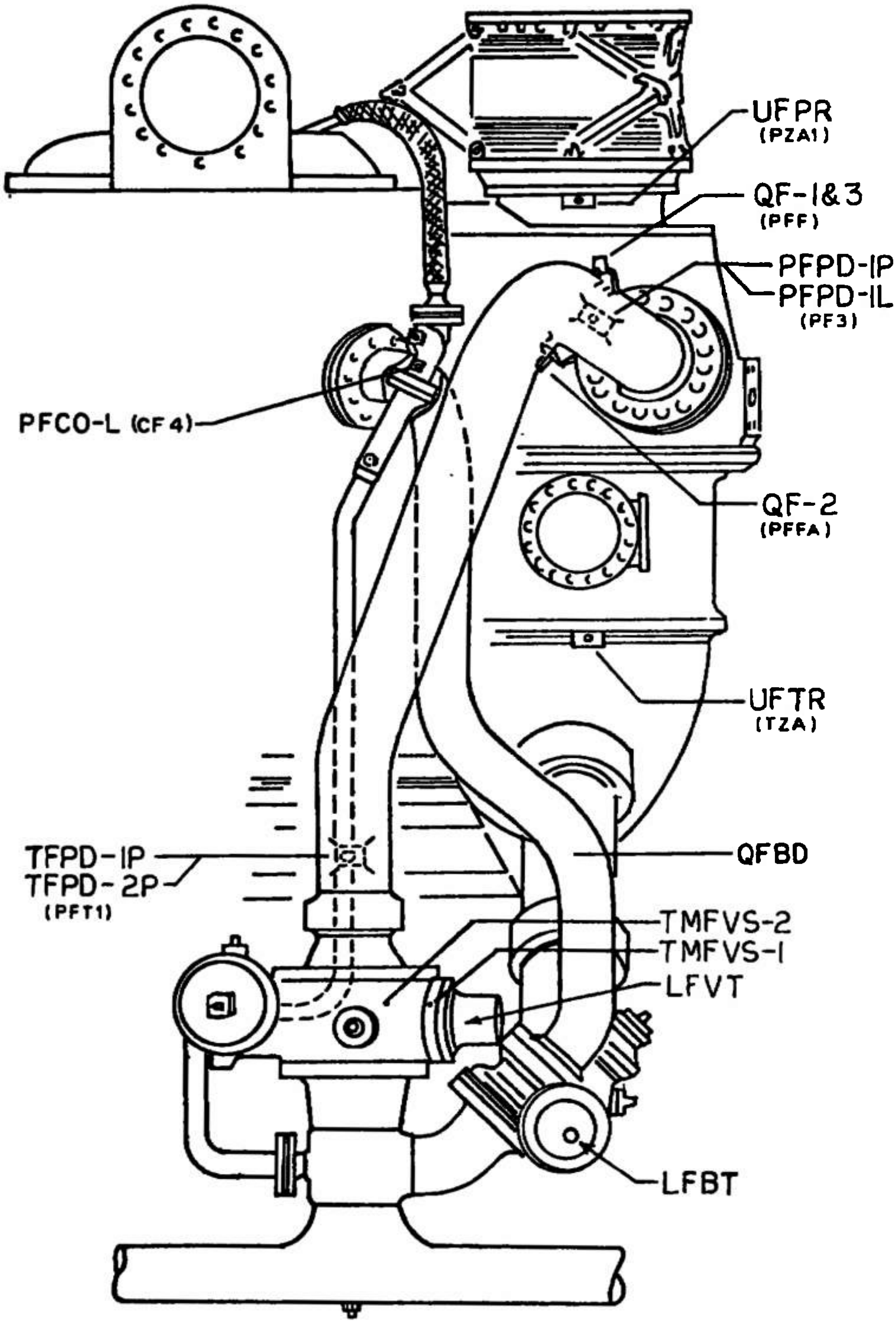
The instrumentation for AEDC tests J4-1902-13 through J4-1902-15 is tabulated in Table III-1. The location of selected major engine instrumentation is shown in Fig. III-1.



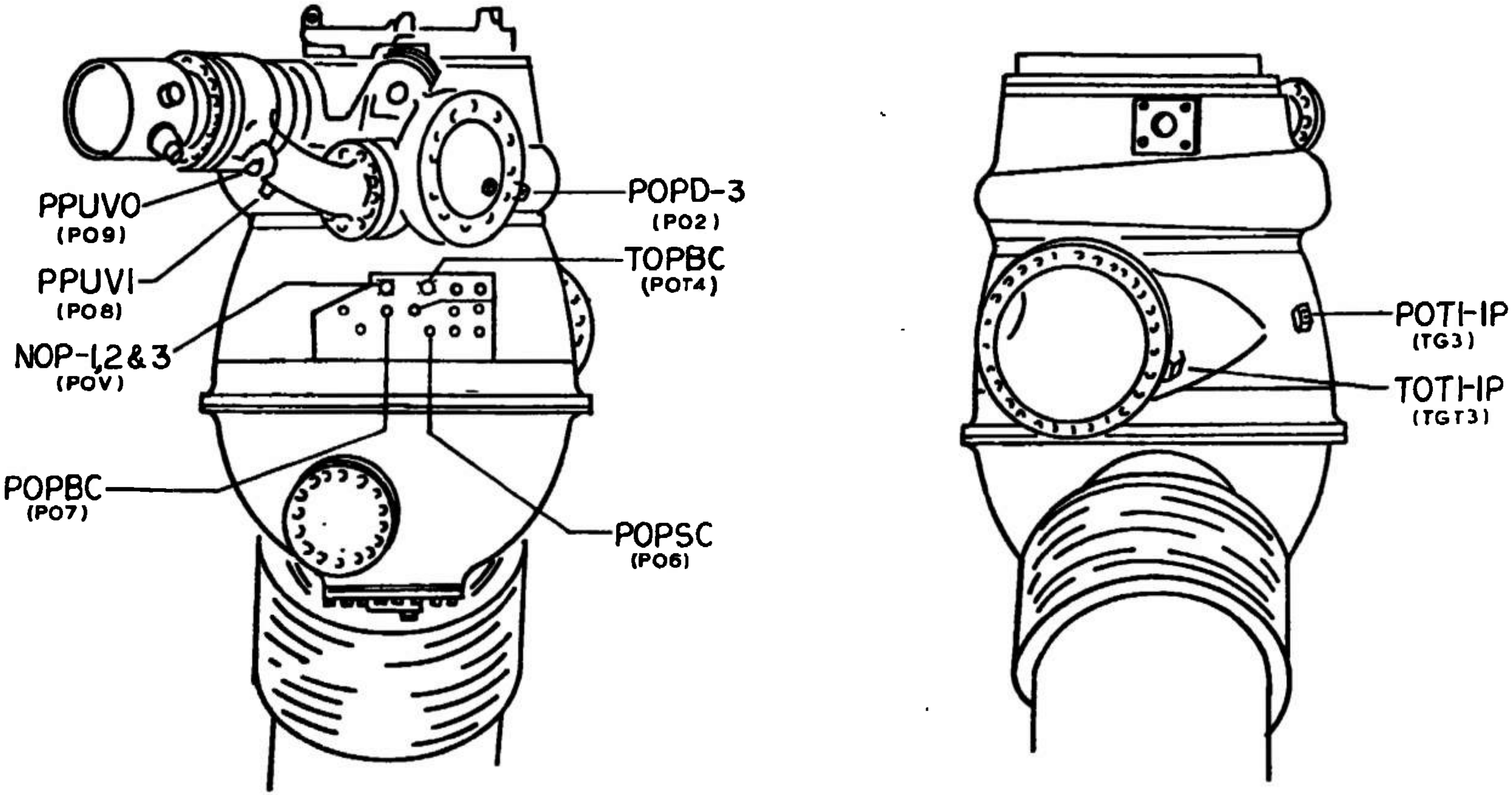
a. General Arrangement
Fig. III-1 Selected Sensor Locations



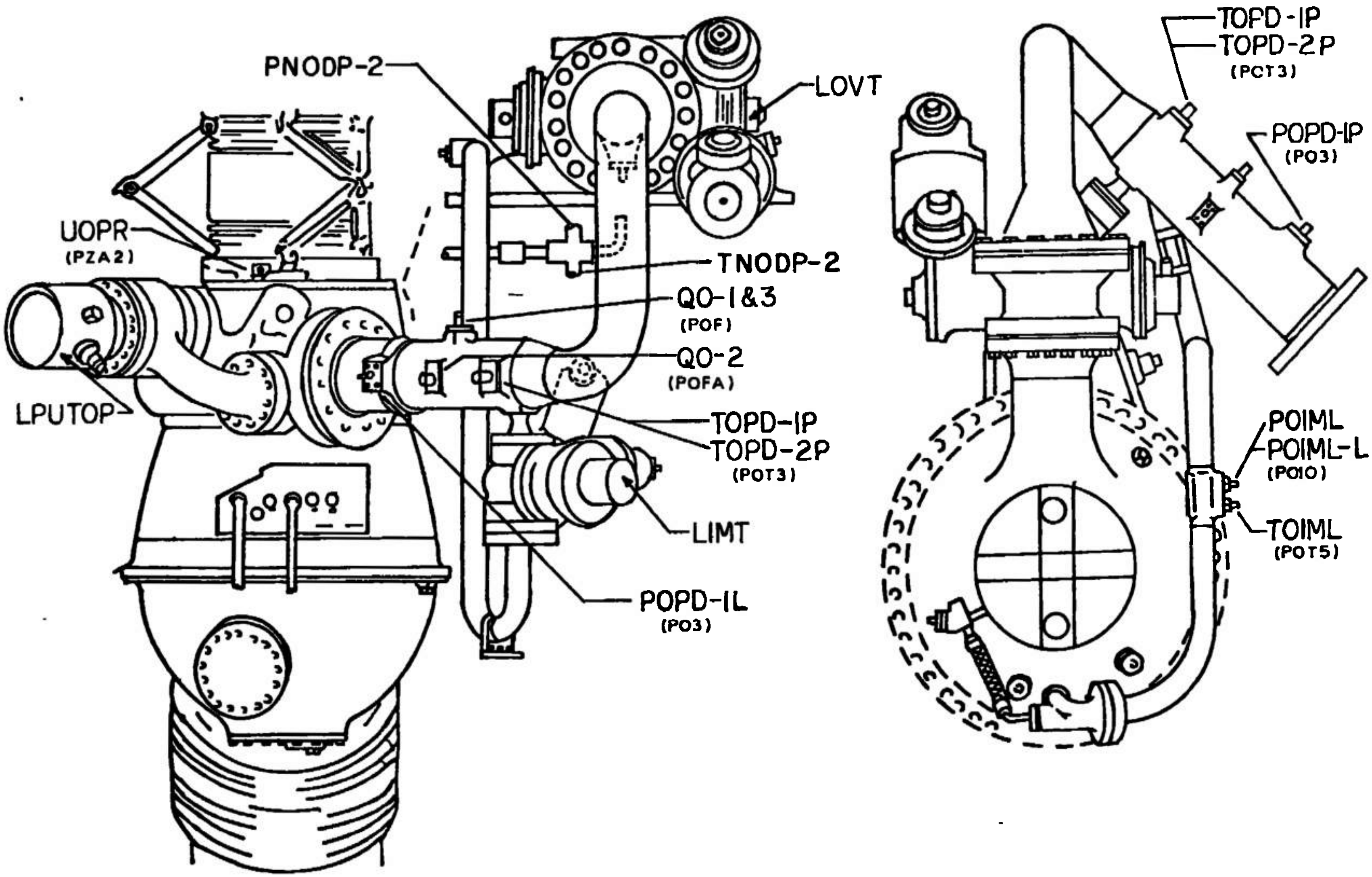
b. Fuel Turbopump Sensor Locations
Fig. III-1 Continued



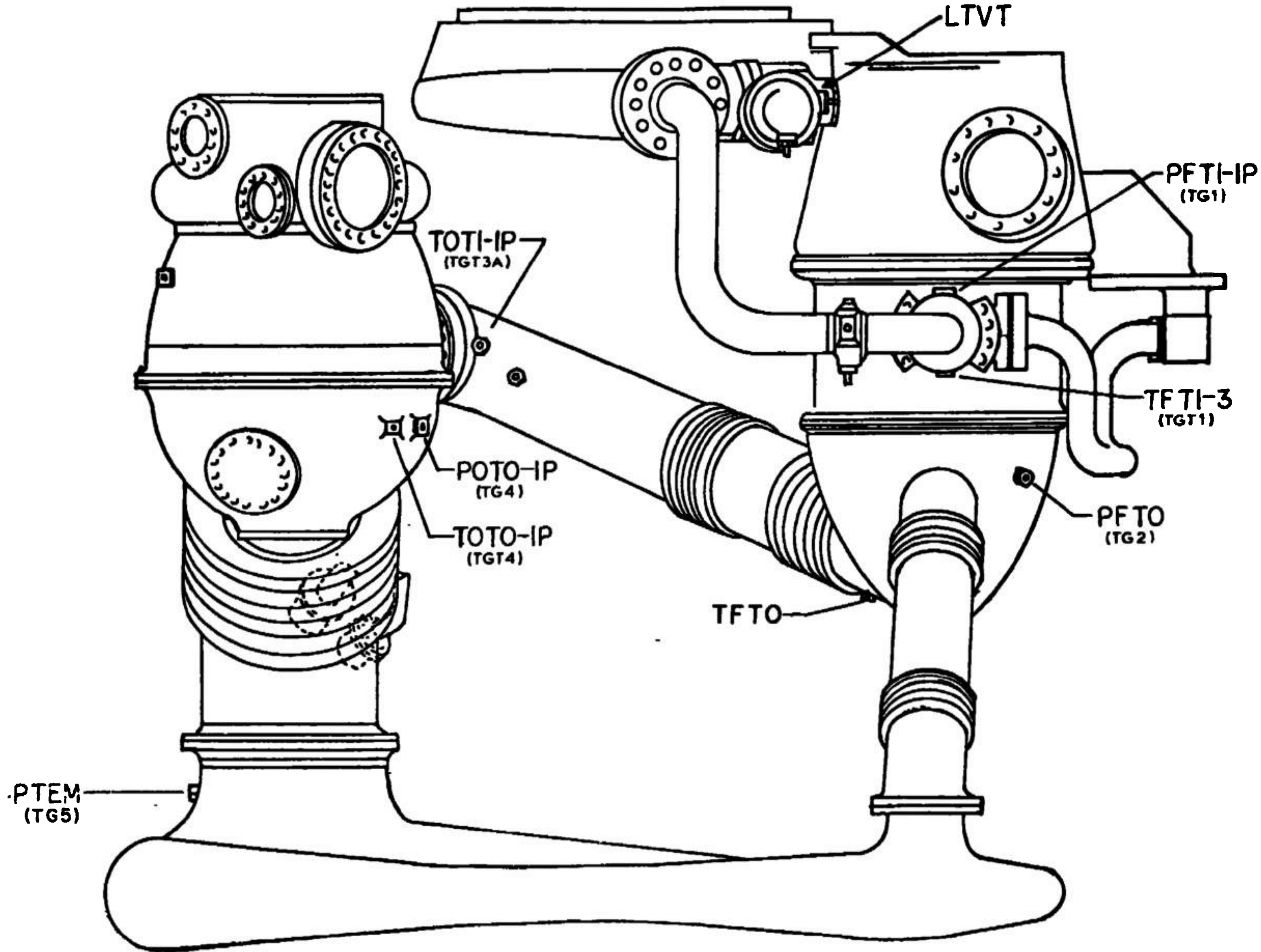
c. Fuel System Sensor Locations
Fig. III-1 Continued



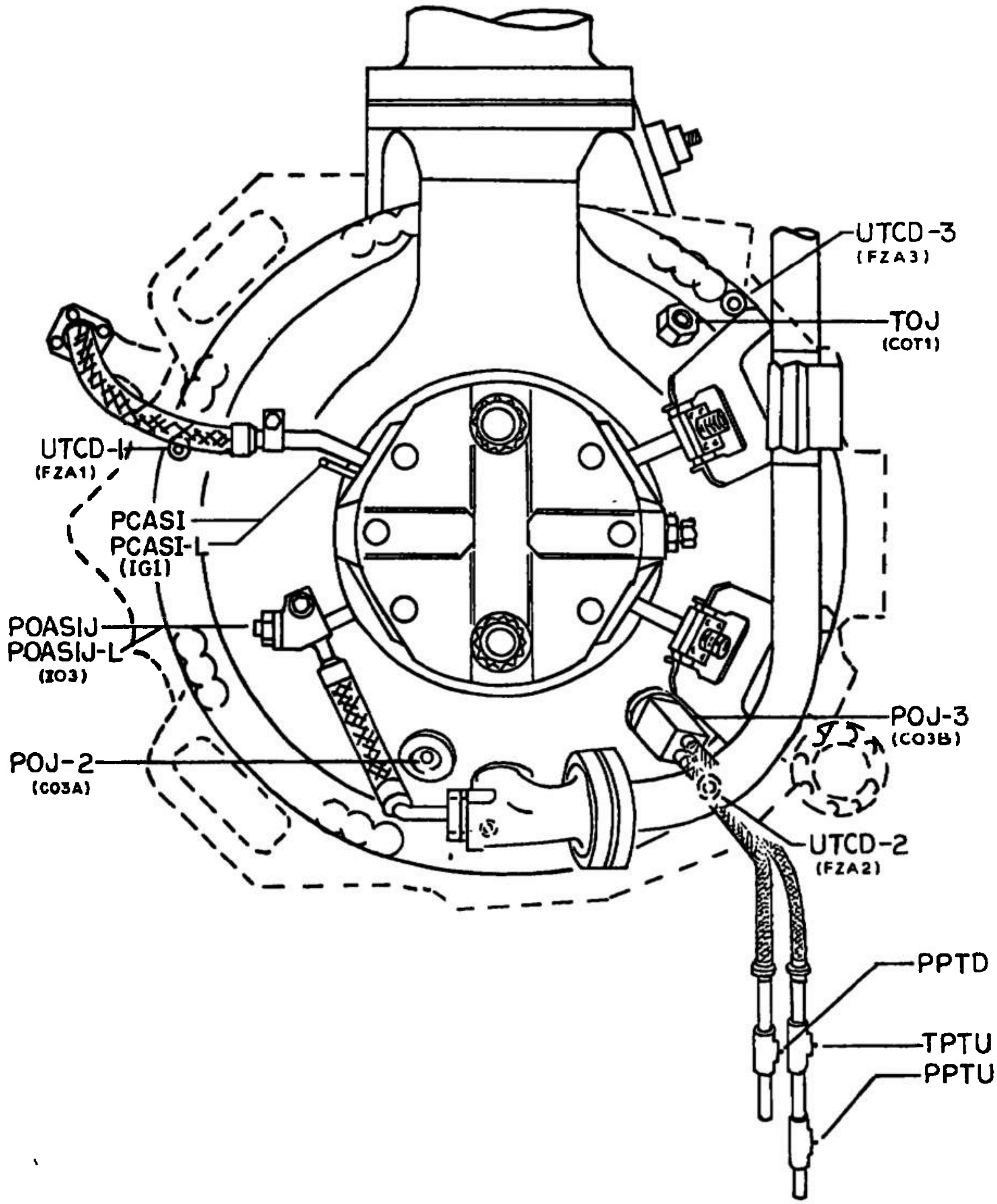
d. Oxidizer Turbopump Sensor Locations
Fig. III-1 Continued



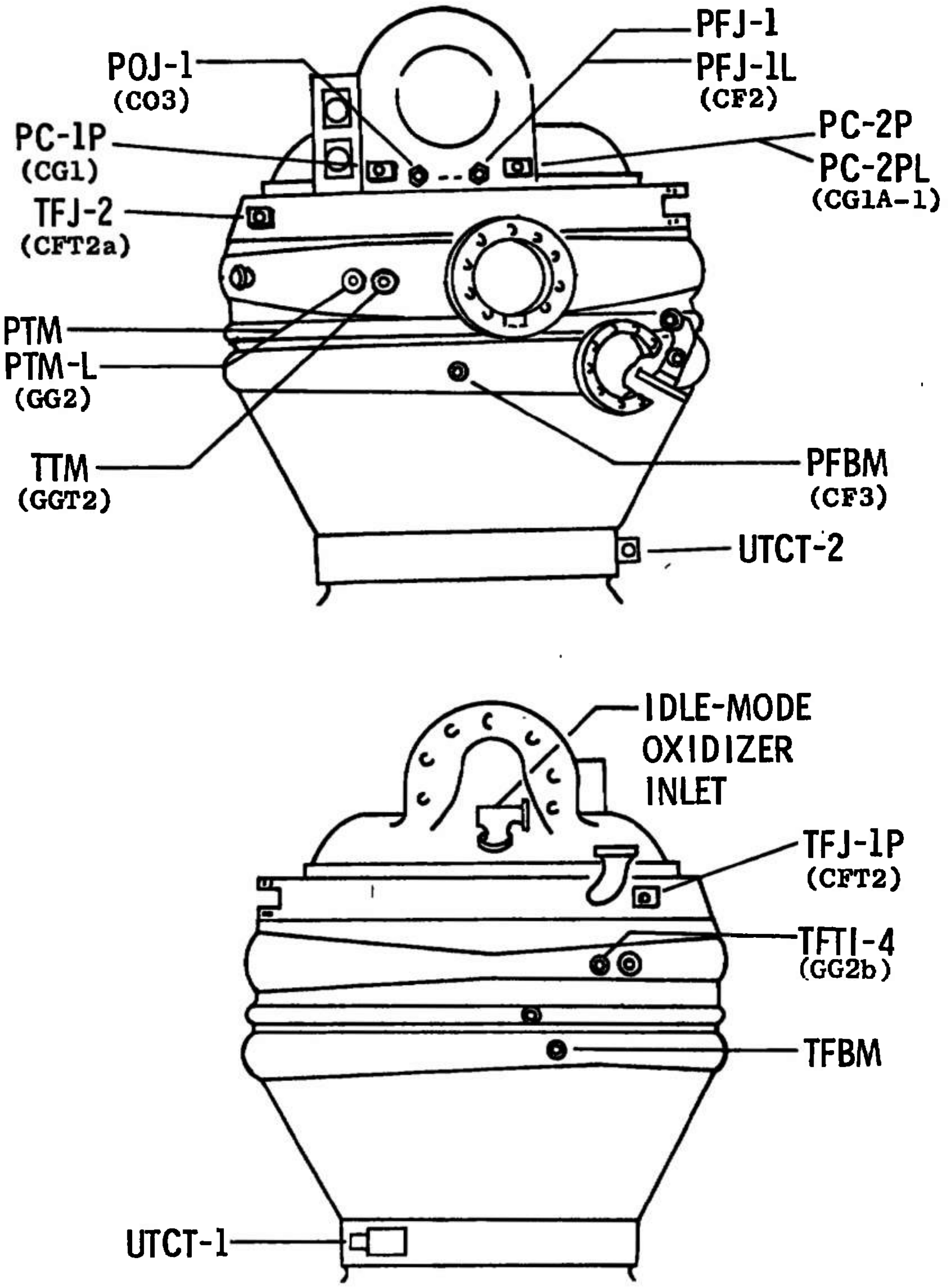
e. Oxidizer System Sensor Locations
Fig. III-1 Continued



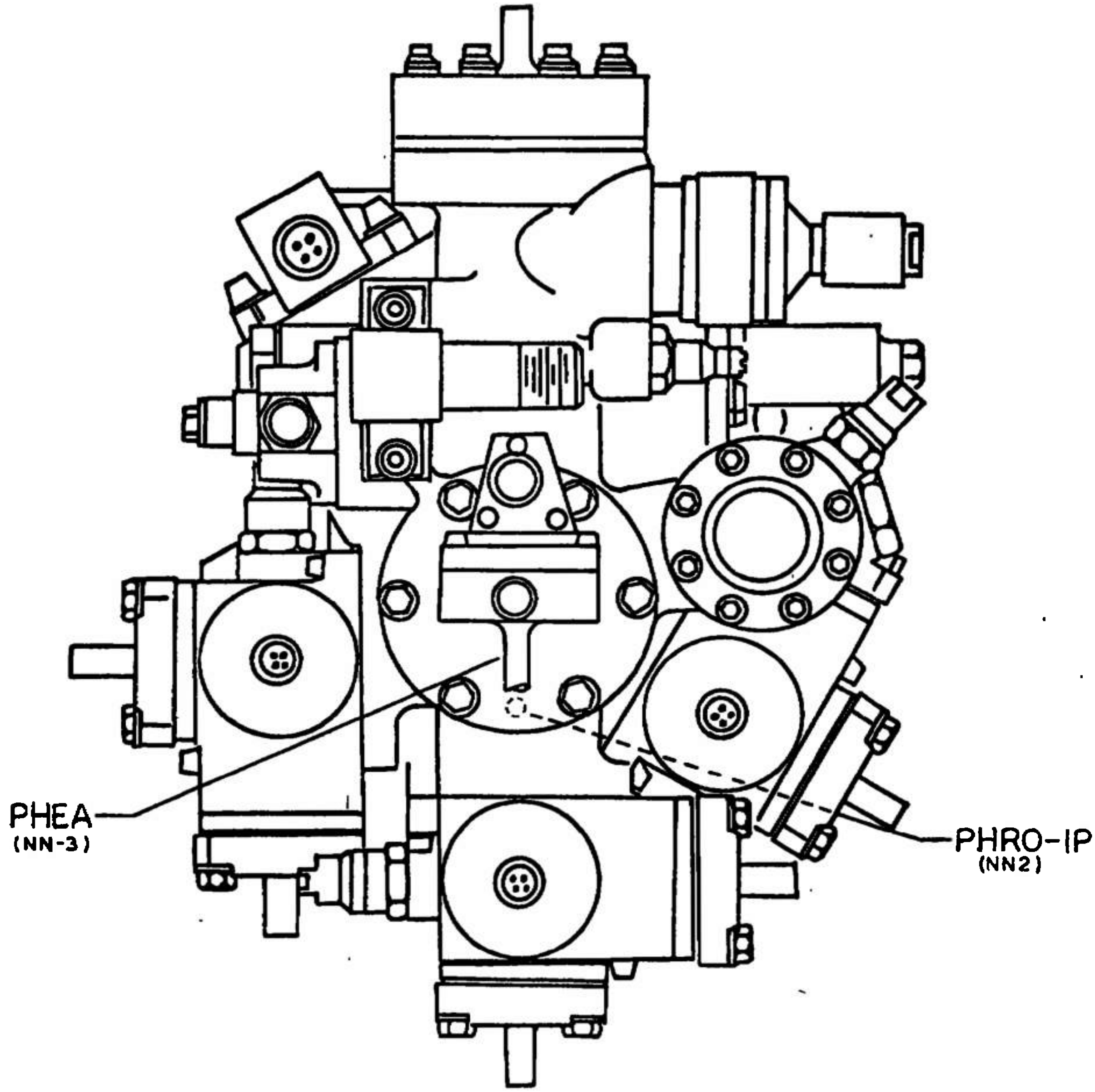
f. Turbine Exhaust System Sensor
Fig. III-1 Continued



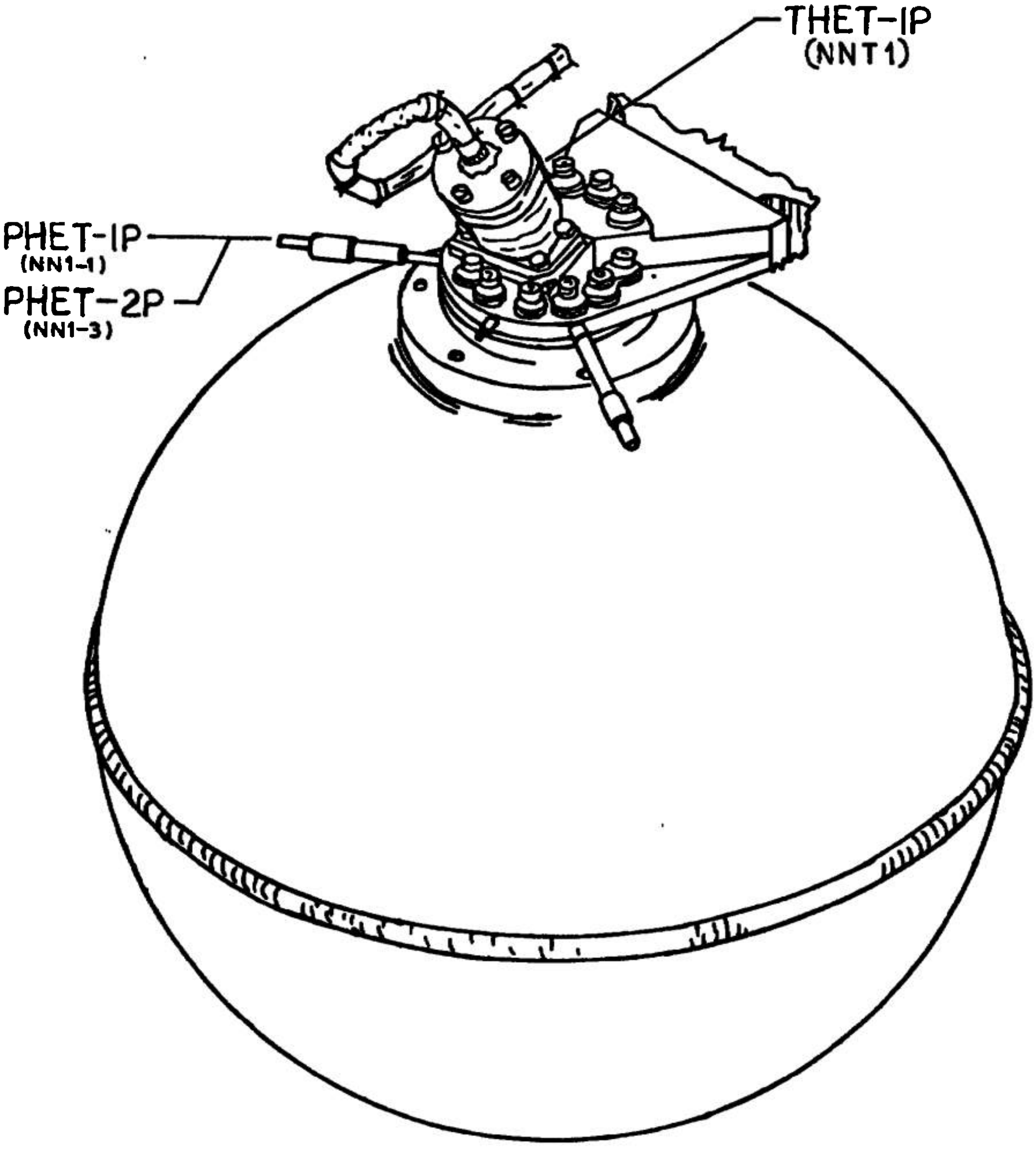
g. Thrust Chamber Injector Sensor Locations
Fig. III-1 Continued



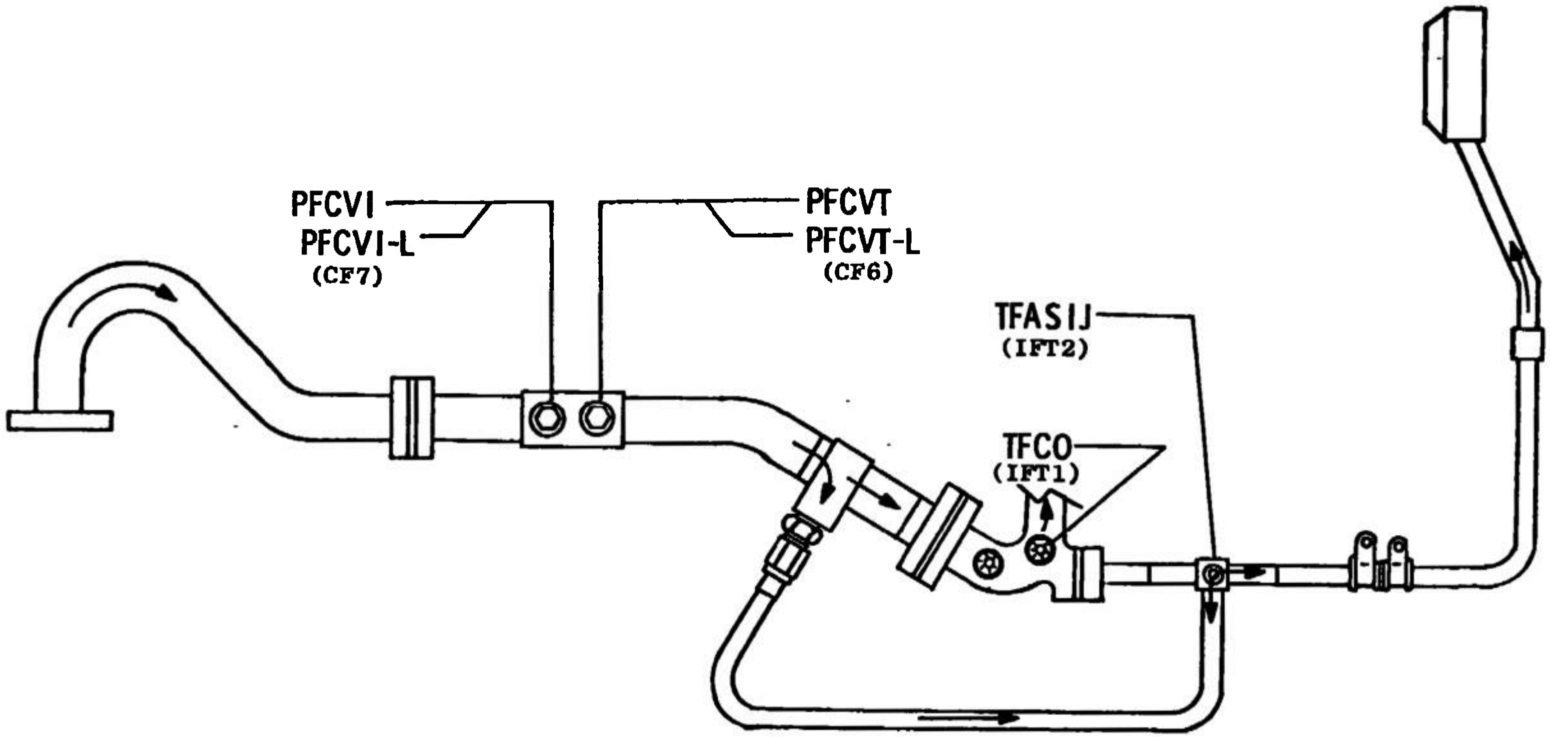
h. Thrust Chamber Sensor Locations
Fig. III-1 Continued



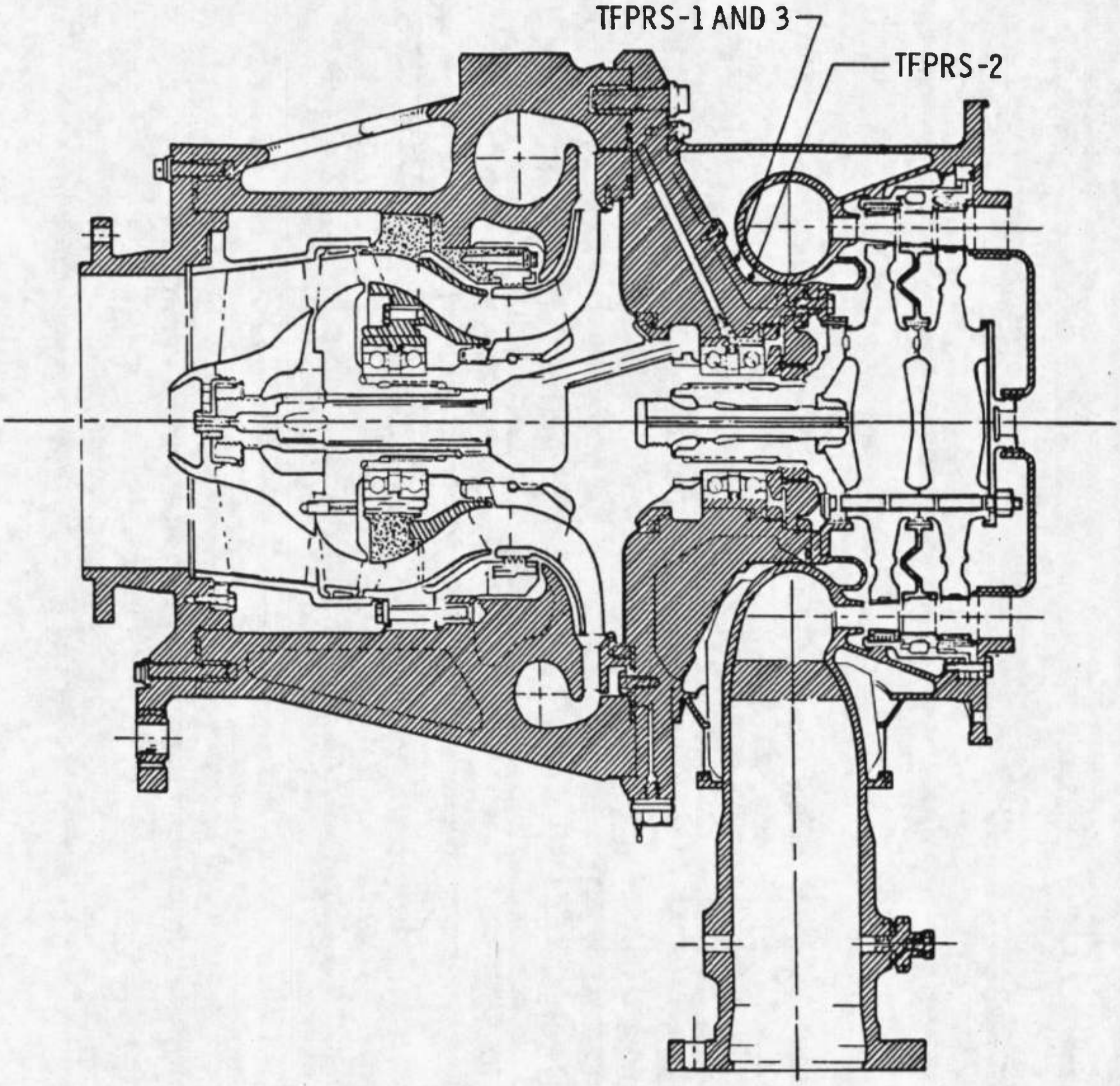
i. Pneumatic Control Package Sensor Locations
Fig. III-1 Continued



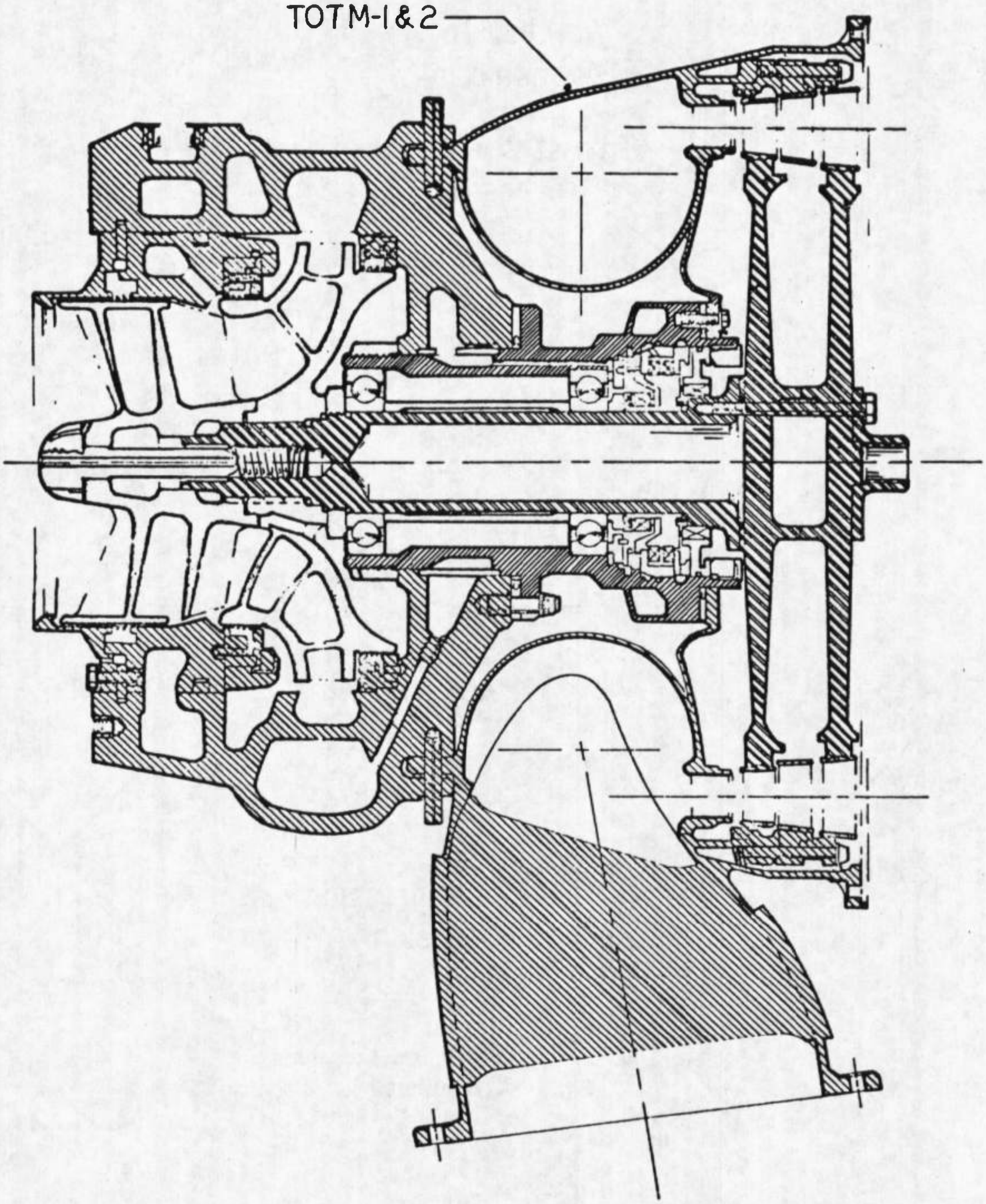
j. Helium Tank Sensor Locations
Fig. III-1 Continued



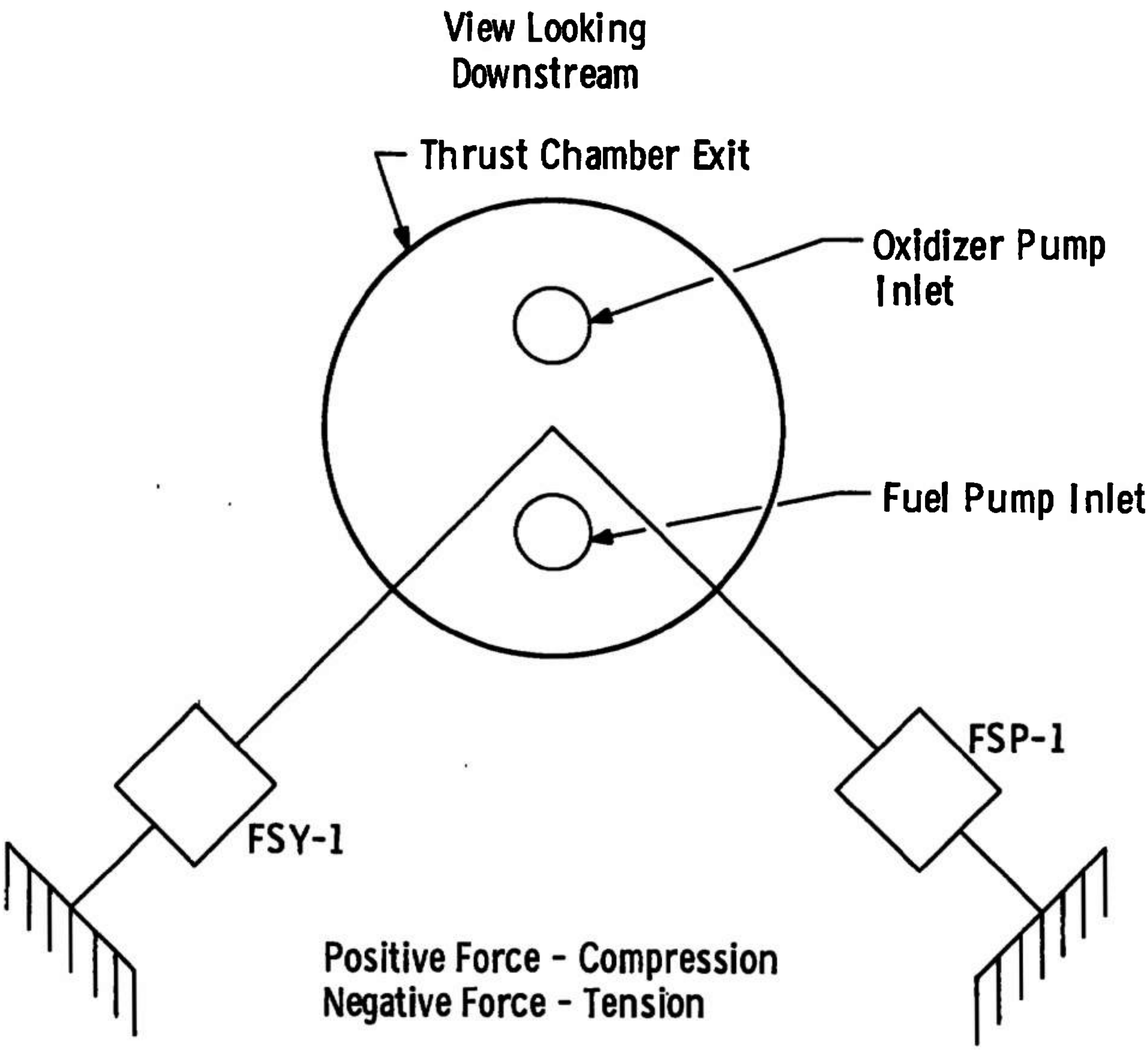
k. Augmented Spark Igniter/Film Coolant Fuel Line Assembly Instrumentation
Fig. III-1 Continued



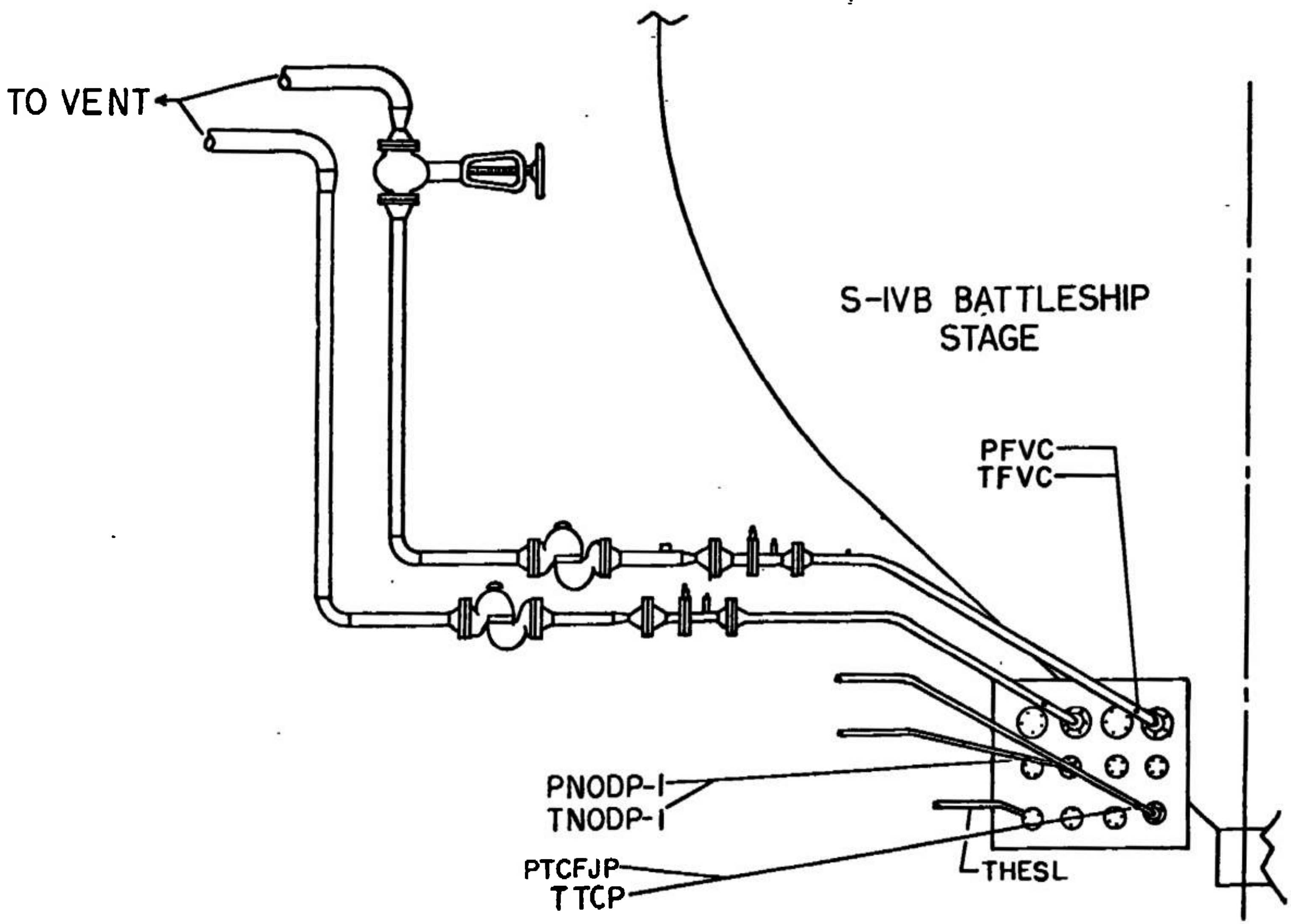
I. Fuel Turbine Sensor Locations
Fig. III-1 Continued



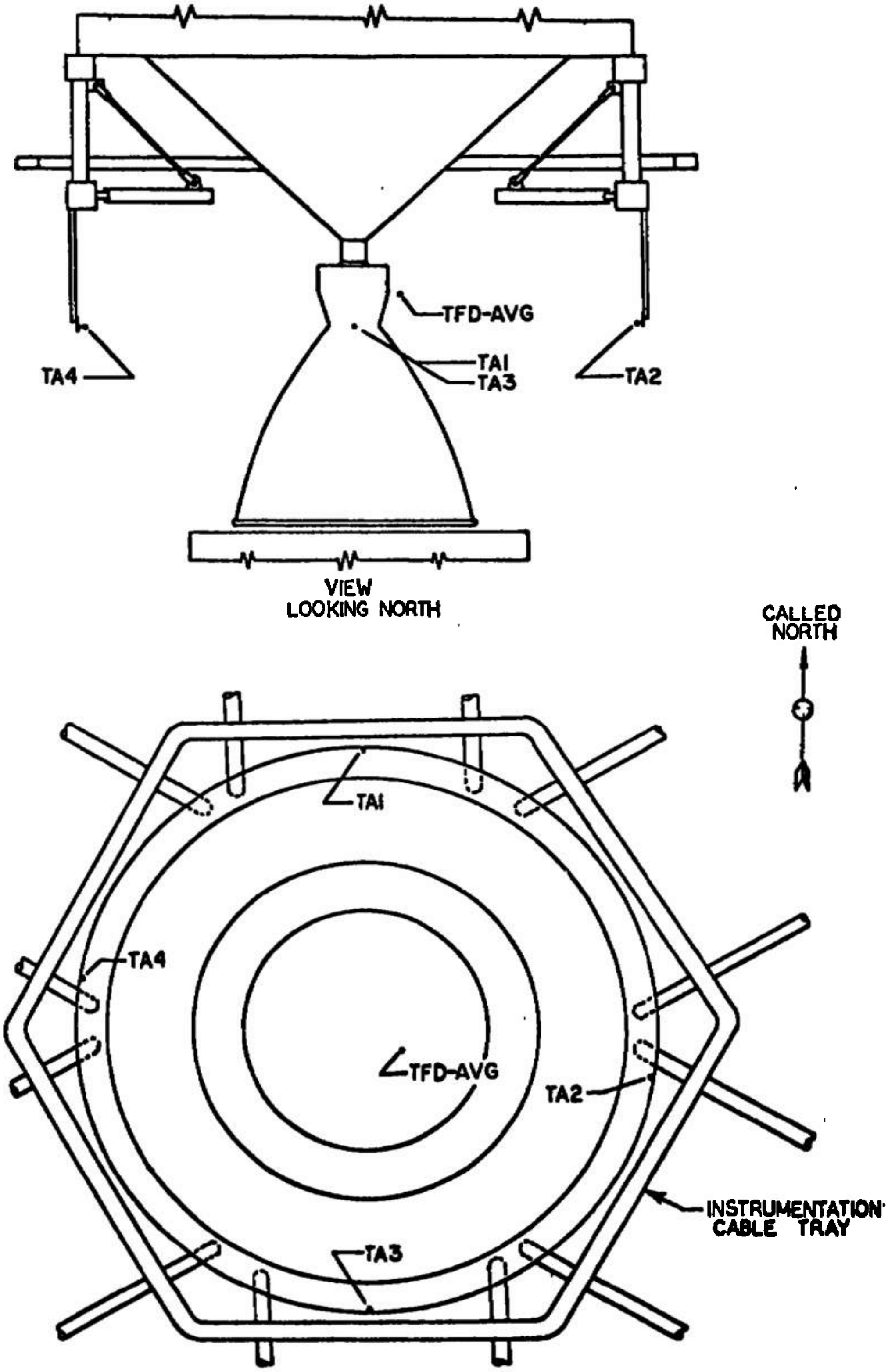
m. Oxidizer Turbine Sensor Locations
Fig. III-1 Continued



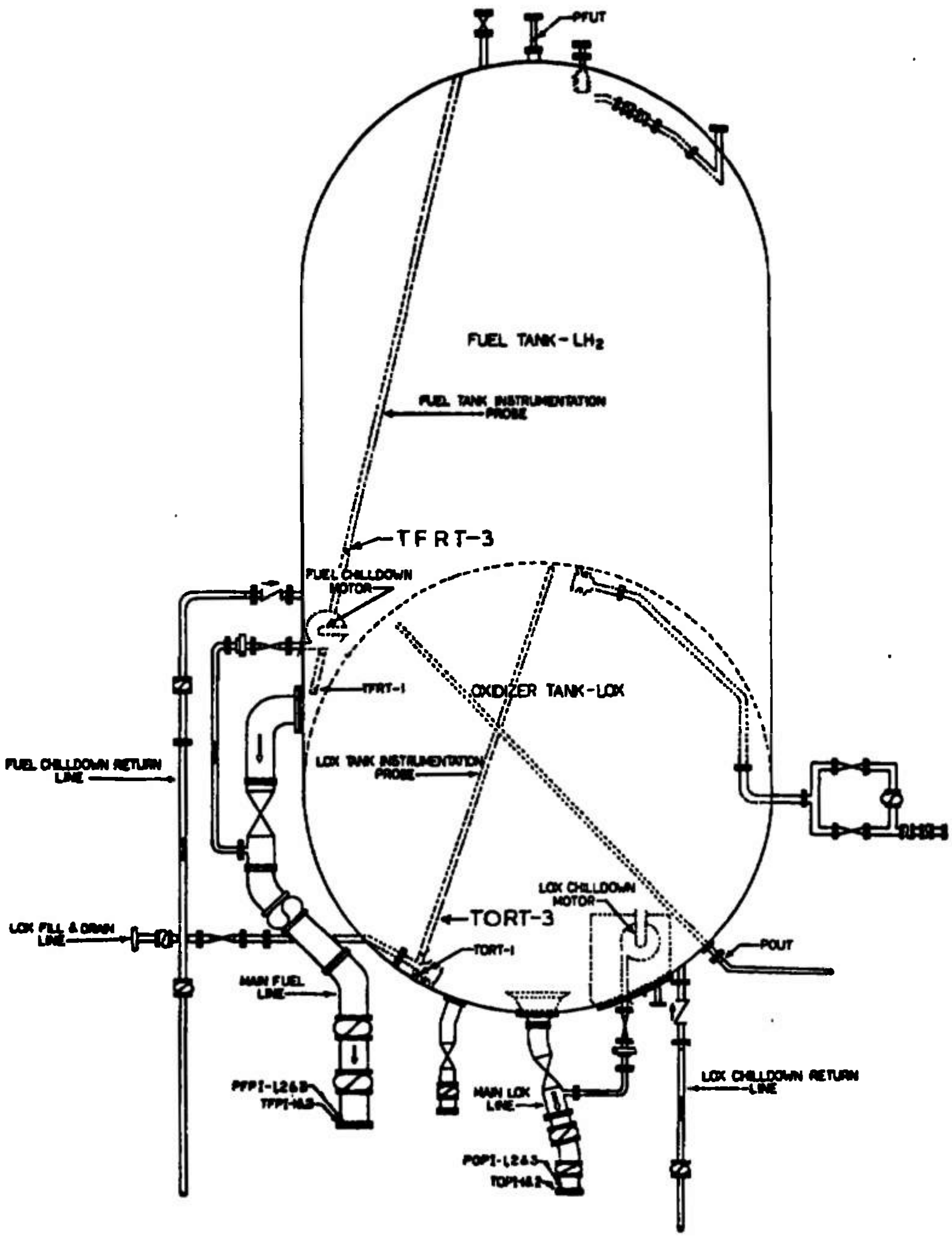
n. Side Load Forces Sensor Locations
Fig. III-1 Continued



o. Customer Connect Panel Sensor Locations
Fig. III-1 Continued



p. Test Cell Ambient Temperature Sensor Locations
Fig. III-1 Continued



q. S-IVB Battleship Sensor Locations
Fig. III-1 Concluded

TABLE III-1
INSTRUMENTATION LIST

AEDC Code	Parameter	Tap	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Current, amp								
ICC	Control		0 to 30	x					
IIC	Ignition		0 to 30	x					
	Event								
EASIS-1	Augmented Spark Igniter 1 Spark		On/Off					x	
EASIS-2	Augmented Spark Igniter 2 Spark		On/Off					x	
EECL	Engine Cutoff Lockin		On/Off	x		x		x	
EECO	Engine Cutoff Signal		On/Off	x		x		x	
EER	Engine Ready Signal		On/Off					x	
EES	Engine Start Command		On/Off	x		x		x	
EESCO	Programmed Duration Cutoff		On/Off					x	
EFBVO	Fuel Bleed Valve Open Limit		On/Off					x	
EFPCO	Fuel Pump Overspeed Cutoff		On/Off					x	
EFPVC	Fuel Prevalve Closed Limit		On/Off	x				x	
EFPVO	Fuel Prevalve Open Limit		On/Off	x				x	
EHCS	Helium Control Solenoid Energized		On/Off	x	x	x		x	
EHGTC	Hot Gas Tapoff Valve Closed Limit		On/Off					x	
EHGTO	Hot Gas Tapoff Valve Open Limit		On/Off					x	
EID	Ignition Detected		On/Off	x		x		x	
EIDA-1	Ignition Detect Amplifier 1		On/Off					x	
EIDA-2	Ignition Detect Amplifier 2		On/Off					x	
EIMCS	Idle-Mode Control Solenoid Energized		On/Off	x		x		x	
EIMVC	Idle-Mode Valve Closed Limit		On/Off					x	
EIMVO	Idle-Mode Valve Open Limit		On/Off					x	
EMCL	Main-Stage Cutoff Lockin		On/Off	x		x		x	
EMCO	Main-Stage Cutoff Signal		On/Off	x		x			
EMCS	Main-Stage Control Solenoid		On/Off	x		x		x	
EMD-1	Main Stage 1 "OK" Depressurized		On/Off	x		x		x	
EMD-2	Main Stage 2 "OK" Depressurized		On/Off	x		x		x	
EMFVC	Main Fuel Valve Closed Limit		On/Off					x	
EMFPVO	Main Fuel Valve Open Limit		On/Off					x	
EMOVC	Main Oxidizer Valve Closed		On/Off					x	
EMOVO	Main Oxidizer Valve Open Limit		On/Off					x	
EMP-1	Main Stage 1 "OK" Pressurized		On/Off	x		x		x	
EMP-2	Main-Stage 2 "OK" Pressurized		On/Off	x				x	
EMPCO	Main-Stage Pressure Cutoff Signal		On/Off					x	
EMS	Main-Stage Start Signal		On/Off					x	
EMSCO	Main-Stage Programmed Duration Cutoff		On/Off					x	
EMSS	Main-Stage Start Solenoid Energized		On/Off	x	x	x		x	

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap	Range	Digital Data System	Magnetic Tape	Oscillograph	Strip Chart	Event Recorder	X-Y Plotter
	Event								
EOBVO	Oxidizer Bleed Valve Open Limit		On/Off					x	
EOCO	Observer Cutoff Signal		On/Off					x	
EOPCO	Oxidizer Pump Overspeed Cutoff Signal		On/Off					x	
EOPVC	Oxidizer Prevalve Closed Limit		On/Off	x				x	
EOPVO	Oxidizer Prevalve Open Limit		On/Off	x				x	
EOTCO	Fuel Turbine Over-Temperature Cutoff		On/Off					x	
ERASIS-1	Augmented Spark Igniter 1 Spark Rate		On/Off			x			
ERASIS-2	Augmented Spark Igniter 2 Spark Rate		On/Off			x			
ESTCO	Start "OK" Timer Cutoff Signal		On/Off					x	
ETCBC	Thrust Chamber Bypass Valve Closed		On/Off					x	
ETCBO	Thrust Chamber Bypass Valve Open		On/Off					x	
EVSC-1	Vibration Safety Counts 1		On/Off			x			
EVSC-2	Vibration Safety Counts 2		On/Off			x			
EVSC-3	Vibration Safety Counts 3		On/Off			x			
	Flows, gpm								
QF-1	Engine Fuel	PFF	0 to 11,000	x					
QF-2	Engine Fuel	PFFa	0 to 11,000	x	x	x			x
QF-3	Engine Fuel	PFF	0 to 11,000			x			
QO-1	Engine Oxidizer	POF	0 to 3,600	x					
QO-2	Engine Oxidizer	POFa	0 to 3,600	x	x	x			
QO-3	Engine Oxidizer	POF	0 to 3,600			x			
	Forces, lbf								
FSP-1	Side Load (Pitch)		±20,000	x		x			
FSY-1	Side Load (Yaw)		±20,000	x		x			
	Position, percent open								
LFBT	Thrust Chamber Bypass Valve		0 to 100	x		x			
LFVT	Main Fuel Valve		0 to 100	x		x			
LIMT	Idle-Mode/Augmented Spark Igniter Oxidizer Valve		0 to 100	x		x			
LOVT	Main Oxidizer Valve		0 to 100	x		x			
LPUTOP	Propellant Utilization Valve		5 v	x		x	x		
LTVT	Hot Gas Tapoff Valve		0 to 100	x		x			

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Pressure, psia								
PA-1	Test Cell		0 to 0.5	x					
PA-2	Test Cell		0 to 1.0	x					
PA-3	Test Cell		0 to 5.0	x		x			
PC-1P	Thrust Chamber	CG1	0 to 1500	x					
PC-2P	Thrust Chamber	CG1a-2	0 to 1500	x		x	x		
PC-2PL	Thrust Chamber	CG1a-1	0 to 50	x		x			
PCASI	Augmented Spark Igniter Chamber	IG1	0 to 1500	x					
PCASI-L	Augmented Spark Igniter Chamber	IG1	0 to 50	x		x			
PFBM	Thrust Chamber Bypass Manifold	CF3	0 to 1500	x					
PFCO	Film Coolant Orifice	CF4	0 to 2000	x					
PFCO-L	Film Coolant Orifice	CF4	0 to 50	x					
PFCVI	Film Coolant Venturi Inlet	CF7	0 to 2000	x					
PFCVI-L	Film Coolant Venturi Inlet	CF7	0 to 50	x					
PFCVT	Film Coolant Venturi Throat	CF6	0 to 200	x					
PFCVT-L	Film Coolant Venturi Throat	CF6	0 to 50	x					
PFJ-1	Fuel Injection	CF2	0 to 1500	x		x			
PFJ-1L	Fuel Injection	CF2	0 to 50	x					
PFMI	Fuel Jacket Manifold Inlet	CF1	0 to 2000	x					
PFMI-L	Fuel Jacket Manifold Inlet	CF1	0 to 50	x					
PFPBC	Fuel Pump Balance Piston Cavity	PF5	0 to 2000	x		x	x		
PFPBS	Fuel Pump Balance Piston Sump	PF4	0 to 1000	x		x	x		
PFPD-1L	Fuel Pump Discharge	PF3	0 to 50	x					
PFPD-1P	Fuel Pump Discharge	PF3	0 to 2500	x			x		
PFPD-2	Fuel Pump Discharge	PF2	0 to 3000	x	x	x			x
PFPI-1	Fuel Pump Inlet	PF1	0 to 100	x					x
PFPI-2	Fuel Pump Inlet		0 to 100	x					x
PFPI-3	Fuel Pump Inlet	PF1a	0 to 100	x	x	x			
PFPRB	Fuel Pump Rear Bearing Coolant	PF7	0 to 1000	x			x		
PFPS	Fuel Pump Interstage	PF6	0 to 1000	x		x	x		
PFPSI	Fuel Pump Shroud		0 to 1500				x		
PFTI-1P	Fuel Turbine Inlet	TG1	0 to 1000	x		x			
PFTO	Fuel Turbine Outlet	TG2	0 to 200	x					
PFTSC	Fuel Turbine Seal Cavity	TG10	0 to 500	x					
PFUT	Fuel Ullage Tank		0 to 100	x					
PFVC	Fuel Repressurization at Customer Connect Panel		0 to 2000	x					
PFVI	Fuel Repressurization Nozzle Inlet	KHP1	0 to 2000	x					
PFVL	Fuel Repressurization Nozzle Throat	KHP2	0 to 1000	x					
PHEA	Helium Accumulator	KH3	0 to 750	x					
PHES	Helium Supply		0 to 5000	x					

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap	Range	Digital Data System	Magnetic Tape	Oscillograph	Strip Chart	Event Recorder	X-Y Plotter
	Pressure, psia								
PHET-1P	Helium Tank	NH1-1	0 to 5000	x					x
PHET-2P	Helium Tank	NH1-3	0 to 5000	x					
PHRO-1P	Helium Regulator Outlet	NH2	0 to 750	x					
PNODP-1	Oxidizer Dome Purge at Customer Connect Panel		0 to 750	x					
*PNODP-2	Oxidizer Dome Purge at Customer Connect Panel		0 to 1500	x					
POASIJ	Augmented Spark Igniter Oxidizer Injection	IO3	0 to 1500	x		x			
POASIJ-L	Augmented Spark Ignitor Oxidizer Injection	IO3	0 to 50	x					
POIML	Oxidizer Idle Mode Line	PO10	0 to 2000	x					
POIML-L	Oxidizer Idle Mode Line	PO10	0 to 50	x					
POJ-1	Oxidizer Injection	CO3	0 to 1500	x					
POJ-2	Oxidizer Injection	CO3a	0 to 2000	x		x			
POJ-3	Oxidizer Injection Manifold	CO3b	0 to 5000		x	x			
POPBC	Oxidizer Pump Bearing Coolant	PO7	0 to 500	x					
POPD-1L	Oxidizer Pump Discharge	PO3	0 to 50	x					
POPD-1P	Oxidizer Pump Discharge	PO3	0 to 2500	x					
POPD-3	Oxidizer Pump Discharge	PO2	0 to 3000		x				
POPI-1	Oxidizer Pump Inlet	PO1	0 to 100	x					x
POPI-2	Oxidizer Pump Inlet		0 to 100	x					x
POPI-3	Oxidizer Pump Inlet	PO1a	0 to 100	x	x	x			
POPSC	Oxidizer Pump Primary Seal Cavity	PO6	0 to 50	x					
POTI-1P	Oxidizer Turbine Inlet	TG3	0 to 200	x					
POTO-1P	Oxidizer Turbine Outlet	TG4	0 to 100	x					
POUT	Oxidizer Ullage Tank		0 to 100	x					
PPTD	Photocon Cooling Water (Downstream)		0 to 100	x					
PPTU	Photocon Cooling Water (Upstream)		0 to 100	x					
PPUVI	Propellant Utilization Valve Inlet	PO8	0 to 2000	x					
PPUVO	Propellant Utilization Valve Outlet	PO9	0 to 1000	x					
PTCFJP	Thrust Chamber Fuel Jacket Purge		0 to 200	x					
PTEM	Turbine Exhaust Manifold	TG5	0 to 50	x					
PTM	Tapoff Manifold	GG2b	0 to 1500	x					
PTM-L	Tapoff Manifold	GG2b	0 to 50	x		x			
	Speeds, rpm								
NFP-1	Fuel Pump	PFV	0 to 33,000		x				
NFP-2	Fuel Pump	PFV	0 to 33,000	x					
NFP-3	Fuel Pump	PFV	0 to 33,000			x			
NOP-1	Oxidizer Pump	POV	0 to 12,000		x				
NOP-2	Oxidizer Pump	POV	0 to 12,000	x					
NOP-3	Oxidizer Pump	POV	0 to 12,000			x			

TABLE III-1 (Concluded)

AEDC Code	Parameter	Tap	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Temperatures, deg F								
TA-1	Test Cell, North		-50 to 800	x					
TA-2	Test Cell, East		-50 to 800	x					
TA-3	Test Cell, South		-50 to 800	x					
TA-4	Test Cell, West		-50 to 800	x					
TECP-1P	Electrical Control Assembly	HST1a	-300 to 200	x					
TFASIJ	Augmented Spark Igniter Fuel Injection	IFT1	-425 to 100	x	x				
TFBM	Thrust Chamber Bypass Manifold		-425 to 100	x					
TFCO	Film Coolant Orifice	IFT1	-425 to -175	x					
TFD-Avg.	Fire Detection Average		0 to 1000	x			x		
TFDFTA	Fire Detect Fuel Turbine Manifold Area		0 to 500	x					
TFDMFVA	Fire Detect Main Fuel Valve Area		0 to 500	x					
TFDMOVA	Fire Detect Main Oxidizer Valve Area		0 to 500	x					
TFDODA	Fire Detect Oxidizer Dome Area		0 to 500	x					
TFDTDA	Fire Detect Tapoff Duct Area		0 to 500	x					
**TFJ-1P	Fuel Injection	CFT2	-425 to -300	x			x		
TFJ-2P	Fuel Injection	CFT2a	-425 to 100	x		x	x		
TFPBS	Fuel Pump Balance Piston Sump	PFT4	-425 to -375	x			x		
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -300	x	x				
TFPD-2P	Fuel Pump Discharge	PFT1	-425 to 100	x					
TFPI-1	Fuel Pump Inlet	KFT2	-425 to -400	x					x
TFPI-2	Fuel Pump Inlet	KFT2a	-425 to 100	x					x
TFPRS-1	Fuel Pump Rear Support		-400 to 1300	x					
TFPRS-1	Fuel Pump Rear Support		-400 to 1300	x					
TFPRS-3	Fuel Pump Rear Support		-400 to 1300	x					
TFRT-1	Fuel Run Tank		-425 to -400	x					
TFRT-3	Fuel Run Tank		-425 to -400	x					
TFTI-3	Fuel Turbine Inlet	TGT1	-300 to 2400	x			x		
TFTI-4	Fuel Turbine Inlet	GGT2 and GG2	-300 to 2000	x		x	x		
TFTO	Fuel Turbine Outlet		-100 to 1200	x					
TFVC	Fuel Repressurization At Customer Connect Panel		-300 to -100	x					
TFVL	Fuel Repressurization Nozzle Inlet	XHFT1	-300 to -100	x					
THET-1P	Helium Tank	HHT1	-200 to 150	x					x
THETA-1	Helium Tank Area		0 to 500	x					
THETA-2	Helium Tank Area		0 to 500	x					
TMFVS-1	Main Fuel Valve Skin (Outer Wall)		-425 to 100	x			x		
TMFVS-2	Main Fuel Valve Skin (Inner Wall)		-425 to 100	x			x		
TMODP-1	Oxidizer Dome Purge at Customer Connect Panel		-250 to 200	x					
*TMODP-2	Oxidizer Dome Purge at Customer Connect Panel		-250 to 200	x					

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Temperatures, deg F								
TOIML	Oxidizer Idle Mode Line	POT5	-300 to 100	x					
TOJ	Oxidizer Injection	COT1	-300 to 1200	x		x			
TOPBC	Oxidizer Pump Bearing Coolant	POT4	-300 to -250	x					
TOPO-1P	Oxidizer Pump Discharge	POT3	-300 to -250	x					
TOPO-2P	Oxidizer Pump Discharge	POT3	-300 to 100	x					
TOPI-1	Oxidizer Pump Inlet	KOT2	-310 to -250	x					x
TOPI-2	Oxidizer Pump Inlet	KOT2a	-310 to 100	x					x
TORT-1	Oxidizer Run Tank		-300 to -205	x					
TORT-3	Oxidizer Run Tank		-300 to -285	x					
TOTI-1P	Oxidizer Turbine Inlet	TGT1	0 to 1200	x					
TOTM-1	Oxidizer Turbine Manifold		-300 to 1000	x					
TOTM-2	Oxidizer Turbine Manifold		-300 to 1000	x					
TOTO-1P	Oxidizer Turbine Outlet	TGT4	0 to 1000	x					
TPIP-1P	Instrumentation Package		-300 to 200	x					
TPTU	Photocon Cooling Water (Upstream)		0 to 300	•					
TTCP	Thrust Chamber Purge		-250 to 200	•					
TTCT-E1	Thrust Chamber Tube (Exit)		-425 to 500	•					
TTCT-E2	Thrust Chamber Tube (Exit)		-425 to 500	•					
TTCT-T1	Thrust Chamber Tube (Throat)		-425 to 500	•			x		
TTCT-T2	Thrust Chamber Tube (Throat)		-425 to 500	x					
TTM	Hot Gas Tapoff Manifold		0 to 2000	x		x	x		
	Peak vibrations, g								
UFPR	Fuel Pump	PZA-1	450		x				
UFTX	Fuel Turbine	V123-2	450		x				
UOPR	Oxidizer Pump Radial	PZA-2	300		•				
UTCO-1	Thrust Chamber Dome	PZA-1a	1400		x	•			
UTCD-2	Thrust Chamber Dome	PZA-2	1400		x	•			
UTCO-3	Thrust Chamber Dome	PZA-3	300		x	x			
UTCT-1	Thrust Chamber Throat		300		x				
UTCO-2	Thrust Chamber Throat		300		x				
	Voltage, v								
VCB	Control Bus		0 to 36	x					
VIB	Ignition Bus		0 to 36	x					
VIDA-1	Ignition Detect Amplifier		9 to 16	x					
VIDA-2	Ignition Detect Amplifier		9 to 16	•					
VPUVEP	Propellent Utilization Valve Telemetry Potentiometer Excitation		0 to 5	•					

*Added after J4-1902-13
**Not required for J4-1902-15

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13. ABSTRACT

Seven firings of the Rocketdyne J-2S rocket engine (S/N J-112-1C) were conducted during test periods J4-1902-13, -14, and -15 on May 15 and 22, and June 4, 1969, respectively. The major objectives of these test periods were: (1) to determine a method of increasing fuel turbine inlet temperature in order to prevent turbine icing and attain stable high thrust idle-mode operation, and (2) to demonstrate post-main-stage transition to low thrust idle model. Changes in injector mixture ratio during high thrust idle-mode operation from 1.55 to 2.02 increased inlet temperature, in general, from 85 to 190°F for the fuel turbine, and from 45 to 95°F for the oxidizer turbine. Stable high thrust idle-mode operation was attained on five firings which had fuel turbine inlet temperatures above 160°F. Satisfactory transition to post-main-stage low thrust idle mode was accomplished.

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1. Rocket motors - J-2S.

2 " " - Performance

4 " " - Ice formation

6-3

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